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Organic Emissions from Ferrous Metallurgical Industries: Compilation of Emission Factors and Control Technologies

by

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Ferroalloys	Stationary Sources	11F
Organic Compounds	Ferrous Metallurgical	07C
Volatility	Industries	20M
Iron and Steel Industry		
Foundries		13I

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ABSTRACT

This report presents a review and analysis of the information and data available in the public domain on organic emissions from the ferrous metallurgy industry, specifically the iron and steel, iron foundry, and ferroalloy industries. Emission sources and information gaps are identified and the credibility ratings of organic emissions data are reported. Organic emission factors for various source categories in these industries are compiled. The content of this report which reflects accurately the present state of knowledge about organic emissions in the iron and steel, iron foundry, and ferroalloy industries may be used as a guide to plan and direct programs for further studies, particularly a program to characterize more precisely those classes of organic species comprising the volatile organic compound category that are released from the potential sources identified.

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1.0 INTRODUCTION

For the most part, environmental studies and regulatory control activities in the iron and steel, iron foundry, and ferroalloy industries have focused on atmospheric particulate emissions and waste water effluent qualities. The studies relating to organic emissions have involved primarily the emission of polynuclear organic materials (POM) from coke production and by-product recovery facilities and lubricant organics from mill rolling and finishing operations. No comprehensive listing of volatile organic compound (VOC) emission factors from the ferrous metallurgy industry has been undertaken.

1.1 PURPOSE AND SCOPE

The original purpose of this study, which the Research Triangle Institute performed as Task 9 under EPA Contract No. 68-02-3152, was to compile a listing of VOC emission factors for the iron and steel, iron foundry, and ferroalloy industries based solely on data and information available in the open literature. This would provide information on the present status of VOC emission data from these industries and offer guidance in selecting further study efforts. The study's objectives were: to identify VOC emission sources within these industries; to quantify and rate the credibility of emission factors for the identified sources; to identify information and database gaps; to assess the effectiveness of VOC control technology in use; and to estimate the effectiveness of alternate control technologies, processes, and operating methods on VOC emissions.

Once the data collection phase was well under way, it became apparent that virtually no specific VOC emissions data were available. Therefore, the decision was made to broaden the species definition to the general category organic emissions. To provide an overview of organic emission factors of various sources within the ferrous metallurgy industry, engineering analyses and estimates have been used to supplement the actual data where data gaps were found. In those cases where significant operating variations occur in a particular process and different types of control systems may influence emissions, several emission factors or range of emission factors are reported.

1.2 CAVEAT

Several comments about the overall credibility of the organic emission factors reported herein are warranted to caution the reader in using the results and in drawing conclusions from the data presented.

First, the paucity of suitable and complete organic emission data made the extensive use of engineering analyses in the estimation of emission factors necessary to provide an overview of the relative organic emissions from the various point sources within the ferrous metallurgy industries. These estimates, which were based on the available fragmentary data whenever possible and on engineering experience, however, should represent emission factors within the range of process and operating variability that might be found for the iron and steel, iron foundry, and ferroalloy industries. In preparing the engineering estimates, we used conservative assumptions so that the derived emission factors might represent estimates on the upper bound of the actual organic emissions. This conservative approach was used to insure that all significant sources of organic emissions in the ferrous metallurgy industries are identified.

Second, the ambiguity inherent in the classifications used for reporting organic emissions data (e.g., hydrocarbons, organic solvents, alphatic organics, aromatic organics, extractable organics, and chromatographicable organics) made consistent and precise identification of the types of organic compound emissions virtually impossible. Consequently, comparative evaluation of organic emission factors from different point sources is uncertain because a consistent basis for calculation of the emission factors could not be established. For example, in some cases the organic emissions (on a mass basis) were expressed as methane which distorts the actual mass emissions of organics and in other cases only POM emissions or extractable emissions were measured and reported.

Although the above problems encountered in this study impact the determination of the true organic emission factors for the point sources within the ferrous metallurgy industry, we believe that the reported emission factors are within the range of process and operating variability that exists for similar sources throughout this industry. Also, this study does reflect accurately the present state of knowledge about organic emissions in the iron and steel, iron foundry, and ferroalloy industries. It can be used as a guide to plan and direct programs for further studies, particularly a program to characterize more precisely those classes of organic species comprising the VOC category that are released from the potential sources identified in this study.

2.0 SUMMARY

The ferrous metallurgy industry which includes the iron and steel, iron foundry, and ferroalloy industries is one of the largest industries in the United States in terms of annual sales, people employed, and production volume.

Over the past decade, however, this industry has been under economic stress; and has undergone a forced state of change, characterized by dramatic shifts in annual production, by major plant closings, by business diversification of major steel corporations, and by a general, although variable, decline in the work force. Although the ferrous metallurgy industry has reduced significantly its production capacity through plant closings, the industry is presently still operating well below its available capacity. Domestic production in the ferrous metallurgy industry over the past two decades has declined to 1981 annual production levels of 120,828,000 tons of steel, 12,390,000 tons of iron foundry castings, and 1,274,000 tons of ferroalloys while domestic consumption of these commodities has shown generally a steady increase over the same period.

Although the ferrous metallurgy industry, specifically the iron and steel industry, is not generally viewed as a major industrial source of volatile organic emissions when compared with the petroleum and organic chemicals industries whose products themselves are largely volatile organics, this industry can be potentially a significant contributor to volatile organic emissions as well (as other classes of organic compounds) because of its very large size and the quantities of organic materials used in the manufacturing process. For example, the iron and steel industry consumes anually more than 343,000 tons of lubricants of which approximately up to 15 percent (Serne and Wilson, 1978) may enter the atmosphere as organic pollutants. This industry is an even larger consumer of other organics such as coal and fuels, a portion of which also become organic pollutants in the atmosphere.

This study was initially directed towards a review and analysis of the information and data available in the public domain on volatile organic emissions from the ferrous metallurgy industry, specifically the iron and steel, iron foundry, and ferroalloy industries. However, the available emission data, for the most part, does not include specific measurements of VOC emissions. Since VOC's represent a component of organic emissions from point sources in the ferrous metallurgy industry, this study examined the broader class of organic emissions from this industry to provide an upper limit or bound on the potential amount of VOC emissions. Therefore, the organic emissions factors reported herein represent more precisely total organic emissions to the atmosphere rather than the more specific VOC emissions.

Table 2-1 presents a summary of the organic emission factors for various source categories in the iron and steel, iron foundry, and ferroalloy industries. The emission factor ratings included in the table reflect the relative credibilities of the emission factors for estimation of organic emissions for the source categories. Also included in Table 2-1 is an estimation of the annual organic emissions from these three industries based on 1981 production data.

The credibility rating assigned to each of the emission factors in Table 2-1 is an estimate of the EF's reliability or credibility as an accurate and representative measure of the emissions for the particular source throughout the industry. These ratings are based on the procedures and scales as set forth in the EPA report "Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections" (EPA, 1980).

As can be seen from Table 2-1, the organic emissions from the iron and steel industry represents nearly 96 percent of the total organic emissions from the whole ferrous metallurgy industry. By-product cokemaking and sinter production account for about 43 percent and 36 percent, respectively, of the total emissions based on emission factors given a C reliability rating. On a per ton of finished product basis, however, the ferro-

TABLE 2-1. SUMMARY OF ORGANIC EMISSION FACTORS FOR THE IRON AND STEEL, IRON FOUNDRY, AND FERROALLOY INDUSTRIES

	Organic emission factor		Normalized organic emission factor	Annual organic emissions
	(lb/ton)[a]	Rating	(lb/ton)[b]	(1981) (tons)
Iron and Steel Industry[c]				
Byproduct cokemaking	11.5	C	3.90	235,614.6
Blast furnace ironmaking	1.98	D	1.17	70,684.4
Sinter production	4.80	C	3.20	193,324.8
Basic oxygen process steelmaking	0.0029	C	0.0018	108.7
Electric arc furnace steelmaking	0.348	C	0.0995	6,011.2
Open hearth furnace steelmaking	0.168	-	0.0188	1,135.8
Hot forming and finishing operations	0.643	D	0.184	11,116.2
Total	-	-	8.57	517,995.7
Iron Foundry Industry[d]				
Cupola furnace melting	0.181	C	0.195	1,208.0
Electric arc furnace melting	0.347	C	0.160	991.2
Inoculation	0.0052	C	0.0013	8.1
Metal pouring and cooling	0.136	C	0.209	1,294.8
Casting shakeout	1.23	C	1.89	11,708.6
Total	-	-	2.46	15,210.7
Ferroalloy Industry[e]				
Open submerged arc furnace smelting				
Silicon metal alloys	51.6[f]	B	10.2	6,508.8[f]
Ferrosilicon alloys	4.4	B	1.86	1,182.7
Ferromanganese alloys	3.72	B	0.340	216.8
Ferrochromium alloys	4.06	D	0.645	410.8
Covered submerged arc furnace smelting				
Ferrosilicon alloys	4.48	B	0.225	143.4
Ferromanganese alloys	0.80	B	0.0479	30.5
Ferrochromium alloys	3.14	D	0.0614	39.1
Total	-	-	13.4	8,529.1
Total for ferrous metallurgy industry:				541,735.5

[a] Emission factors based on ton of process or operation product output (e.g., coke, iron, sinter, etc.).

[b] Emission factors normalized to lb/ton finished product (i.e., total steel products, net castings, total ferroalloys).

[c] 1981 Steel production 120,828,000 tons.

[d] 1981 Iron casting production 12,390,000 tons.

[e] 1981 Ferroalloy production 1,274,000 tons.

[f] Emission factors and annual organic emissions do not include low boiling point (C_1-C_8) hydrocarbons.

[g] Conversion factors: 1.0 lb/ton = 0.5 kg/MT (MT = metric ton = 1.0 Mg) and 1.0 ton = 0.9072 MT.

alloy industry has the highest overall organic emission factor with the iron and steel industry second and the iron foundry industry the lowest. But, the ferroalloy industry has the lowest quantity of organic emissions of three industries because of its low production level.

The organic emission factors summarized in Table 2-1 represent uncontrolled organic emissions which, in some cases, include emissions released to the atmosphere through particulate pollution control devices in current use. With the exception of some by-product cokemaking facilities, the pollution control devices in use are designed primarily to control particulate emissions to the atmosphere. These devices include mainly baghouses, wet scrubbers, and electrostatic precipitators (ESP). Although data on the efficiency of these devices in capturing organic emissions from ferrous metallurgical industry sources is very limited, wet scrubbers, as might be expected, appear to be more effective in organics removal than the other devices. For example, in the ferroalloy industry, scrubber efficiencies for organics of 65 to 88 percent compared to 13 to 65% for baghouses were reported (Westbrook, 1982).

In some cases, changes in production procedures and operating practices have been used to reduce organic emissions. Most notably in the iron and steel industry for example, the use of fresh quench water in the coke quench tower and the restricted use of scrap and mill scale containing high levels of oil contaminants have significantly reduced organic emissions and have been generally adopted as standard practice. Similarily in the iron foundry industry, an increase in the cooling time of castings before mold shakeout significantly reduces organic emissions during shakeout operations (Baldwin, 1980).

3.0 STUDY APPROACH AND METHODOLOGY

This section describes briefly the technical approach and methodology used in conducting this study. Because of the varied and ambiguous terminology used in the literature to identify the types of organic emissions, a brief discussion of terminology is presented first. Then the criteria used to rank the credibility of the organic emissions data is presented followed by a brief description of the technical approach and methods employed.

3.1 DEFINITIONS

The original intent of this study was to focus on volatile organic compound (VOC) emissions from the iron and steel, iron foundry, and ferroalloy industries. In the context of categorizing air pollutants, the term volatile organic compound (VOC) has been adopted (EPA, 1978) as a generic classification for any organic compound that, when released to the atmosphere, can remain long enough to participate in photochemical reactions. This definition focuses on the photochemical activity of a compound rather than on more commonly available information such as boiling point or carbon number. Therefore, the unequivocal classification of an organic compound as a VOC requires information about the compound's photochemical reactivity. However, since the predominant fraction of identified VOC's are compounds with vapor pressures greater than 0.1 mm Hg at standard conditions (20°C and 760 mm Hg pressure), which evaporate rapidly at ambient temperatures, organic compounds with vapor pressures greater than 0.1 mm Hg are frequently considered VOC's in the absence of photochemical reactivity information.

The term organic compound, as used in the VOC definition, is defined as any compound of carbon, except carbonates, metallic carbides, carbon monoxide, carbon dioxide, and carbonic acid. This definition basically includes carbon-containing compounds from simple methane to very complex high molecular weight macromolecules. To be more specific in classifying organic emissions, however, such subclassification terms as hydrocarbons, organic solvents, VOC's, polynuclear organic materials (POM), chromatographicable organics, gravimetric organics, and extractable organics have been used. Unfortunately, these subclasses are not mutually exclusive in that they overlap with some compounds belonging to several different subclasses.

In our review of the literature, it became apparent that the classification and subsequent quantification of reported atmospheric organic emissions as VOC's for the various sources categories within the ferrous metallurgy industry would be virtually impossible. This difficulty which is attributed to the various methods of air sampling and analytical techniques used coupled with a paucity of suitable and complete data precluded consistent classification of organic compounds from the different point sources. For example, in some cases, the organic samples collected were not analyzed for specific classes of constiuents; and, in other cases, the analyses were not specific and were reported as methane equivalents. Also, the different sampling methods employed such as adsorption, absorption (liquid scrubbing) and condensation yield different collection efficiences for the same organic compound types.

As a result of these deficiences in the available data, consistent identification of VOC emissions and quantification of VOC emission factors between source categories could not be obtained. Therefore, the decision was made to broaden the species definition for this study to the general category of organic emissions.

3.2 EMISSION FACTOR CREDIBILITY RATING

The organic emission factors (EF) reported herein have been rated to assign an estimate of their reliability or credibility. The system used here for rating the credibility of the emission factors is based on the procedures and scales as set forth in the EPA report "Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections" (EPA, 1980).

Briefly, this rating process involves the assessment and ranking of two elements -- the quality of the emissions data and the representativeness of the emission factor based on a source category sample to the source category population within the industry -- to arrive at the overall credibility rating of the reported emission factor.

In rating the quality of the organic emissions data, the following scale and criteria were used:

A - Tests performed by a sound methodology and reported in enough detail for adequate validation. These tests are not necessarily EPA reference method tests, although such reference methods are certainly to be used as a guide.

B - Tests that are performed by a generally sound methodology but lack enough detail for adequate validation.

C - Tests that are based on an untested or new methodology or that lack a significant amount of background data.

D - Tests that are based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

The rating of the representativeness of the "sampled" emission factor to the "population" emission factor of the industry's source category is analogous to comparing the width of the confidence interval on a sample statistic. Because of the way an emission factor data base is generated, however, statistical procedures generally cannot be used rigorously to determine confidence intervals for emission factors. Therefore, consideration is given to various factors -- the number of facilities tested, estimate of the number of facilities in the United States, range of emissions in the United States (minimum, maximum), range of emissions for each facility tested (minimum, maximum, and number of tests), and a description of how the sample was chosen (i.e., random, tests for NSPS etc.) and an estimate of whether this may cause bias in the data -- in rating the representativeness of the emission factor.

The rating of these two elements was combined to arrive at an overall credibility rating that is presented with the organic emission factors in this report. The following scale was used for this overall credibility rating:

> A - Excellent. Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category (A category in the emission factor table for which an emission factor has been calculated; generally a single process.) is specific enough to minimize variability within the source category population.
>
> B - Above average. Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. As in the A rating, the source category is specific enough to minimize variability within the source category population.
>
> C - Average. Developed only from A- an B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.
>
> D - Below average. The emisson factor was developed only from A- and B-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population.
>
> E - Poor. The emission factor was developed from C- and D- rated test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population.

3.3 DATA GATHERING AND ANALYSIS

Since the scope of work did not include field monitoring or surveys, this study is based on information and data available in the literature and on engineering estimates. To provide an efficient means of gathering and reviewing information and data from the literature, an overview examination of the ferrous metallurgy industry was used to identify organic inputs and to identify organic emission point sources by tracing the distribution of these organic inputs through the process or facility. This approach was in essence the development of an organic "macro" material balance for a so called "typical" plant or facility within the iron and steel, iron foundry, and ferroalloy industries.

3.4 HYPOTHETICAL PRODUCTION PLANT

To analyze the data and to calculate organic emission factors on a common normalized basis, the concept of a hypothetical plant or facility operation was adopted. This concept of a hypothetical plant was expeditious because of the great variability in process operations and operating practices found from plant to plant. This hypothetical plant was self-sufficient in that it consumed the basic raw materials of the industry without requiring purchase of intermediate materials such as coke and pig iron, and produced the full range of products characteristic of the industry. Also, the hypothetical facility included all major unit operations of the industry. The relative production rates of the various process unit operations in this hypothetical facility reflected the most recent industry-wide production statistics. In the situation where the industry-wide annual production statistics were not consistent with the assumption of facility self-sufficiency, corrections were made to the hypothetical facility's unit operation production rate to maintain facility self-sufficiency. For example, if the domestic production of coke or pig iron was not sufficient for the industry wide production of the finished steel products, the relative production rate of coke and pig iron within the hypothetical integrated steel plant was adjusted to match the production requirements consistent with the production of finished or total products.

4.0 THE IRON AND STEEL INDUSTRY

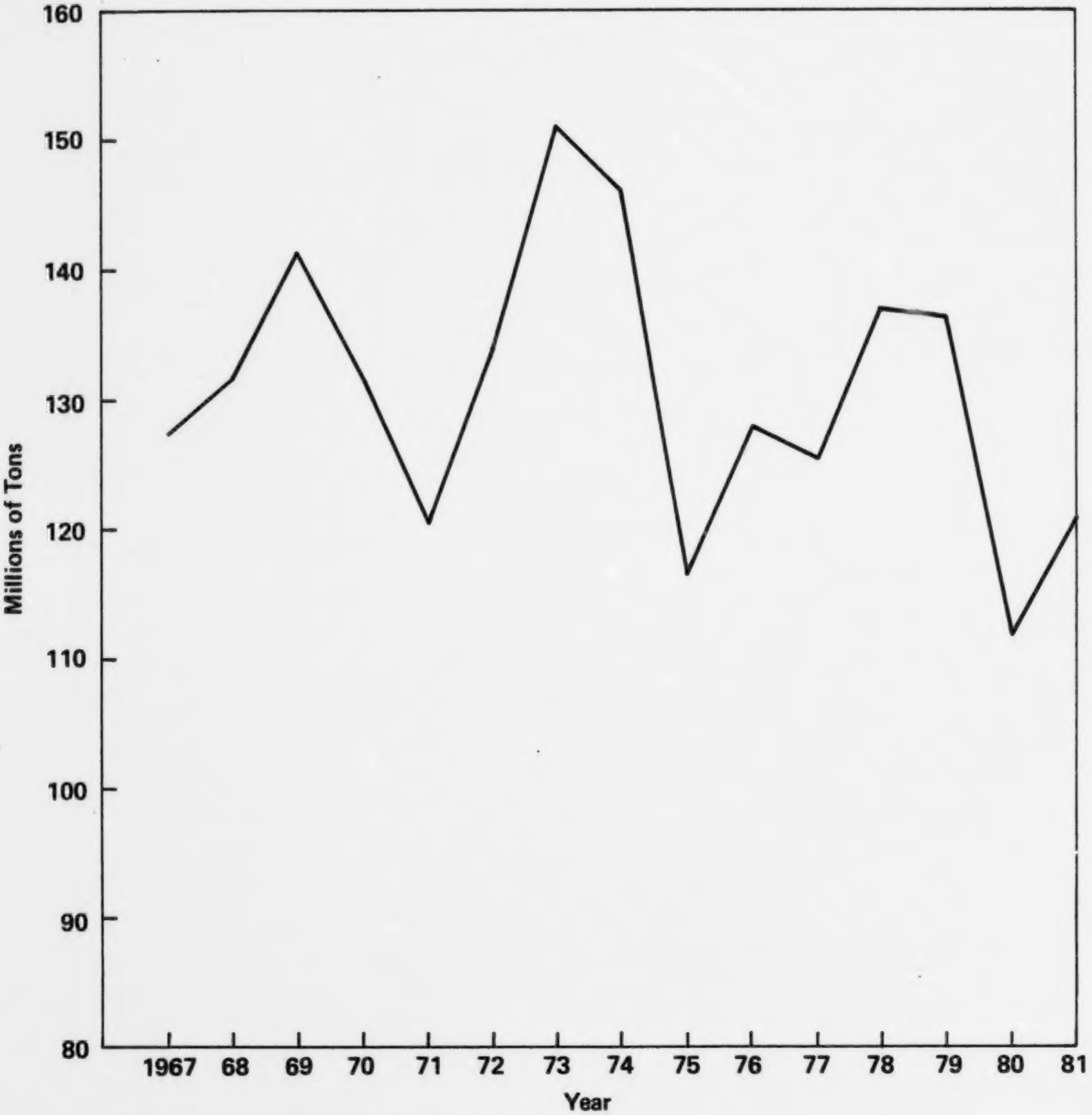
The iron and steel industry is the cornerstone of an industrial society because steel, its major product, is the most widely used single industrial material for the manufacturer of transporation equipment, construction materials, durable goods, defense hardware, and metal containers. This industry supplies a commodity that virtually touches every facet of modern society.

4.1 OVERVIEW

Over the past decade, the iron and steel industry has been in the state of change, characterized by dramatic shifts in annual steel production from a low of 111,835,000 tons in 1980 to a high of 150,799,000 tons in 1973 (AISI, 1982), by major plant closings, by business diversification of major steel corporations, and by a general, although variable decline in the work force. Figure 4-1 which displays the annual steel production in the United States over the period 1967 to 1981 illustrates the volatile nature of domestic steel production.

In 1981, there were over 150 steel producing plants in the United States of which less than 50 were integrated production plants with operations from the blast furnace through rolling mills (AISE, 1982). Table 4-1 lists the integrated steel plants in the United States and their annual steel production capacities. The locations of these integrated steel plants are shown in Figures 4-2 and 4-3. As can be seen from these figures, the integrated steel plants are concentrated in the states of Illinois, Indiana, Michigan, Ohio, and Pennsylvania.

Based on estimated 1981 steel production capacities for speciality steel producers of 11,948,000 tons and for mini/midi steel plants of 13,943,000 tons (AISE, 1982), total annual steel production capacity in the United States, which may vary from year to year depending on the equipment in service, is about 167,246,000 tons. The integrated steel plants listed in Table 4-1 then represent about 85 percent of total U.S. steel production



Source: American Iron and Steel Institute, 1982.

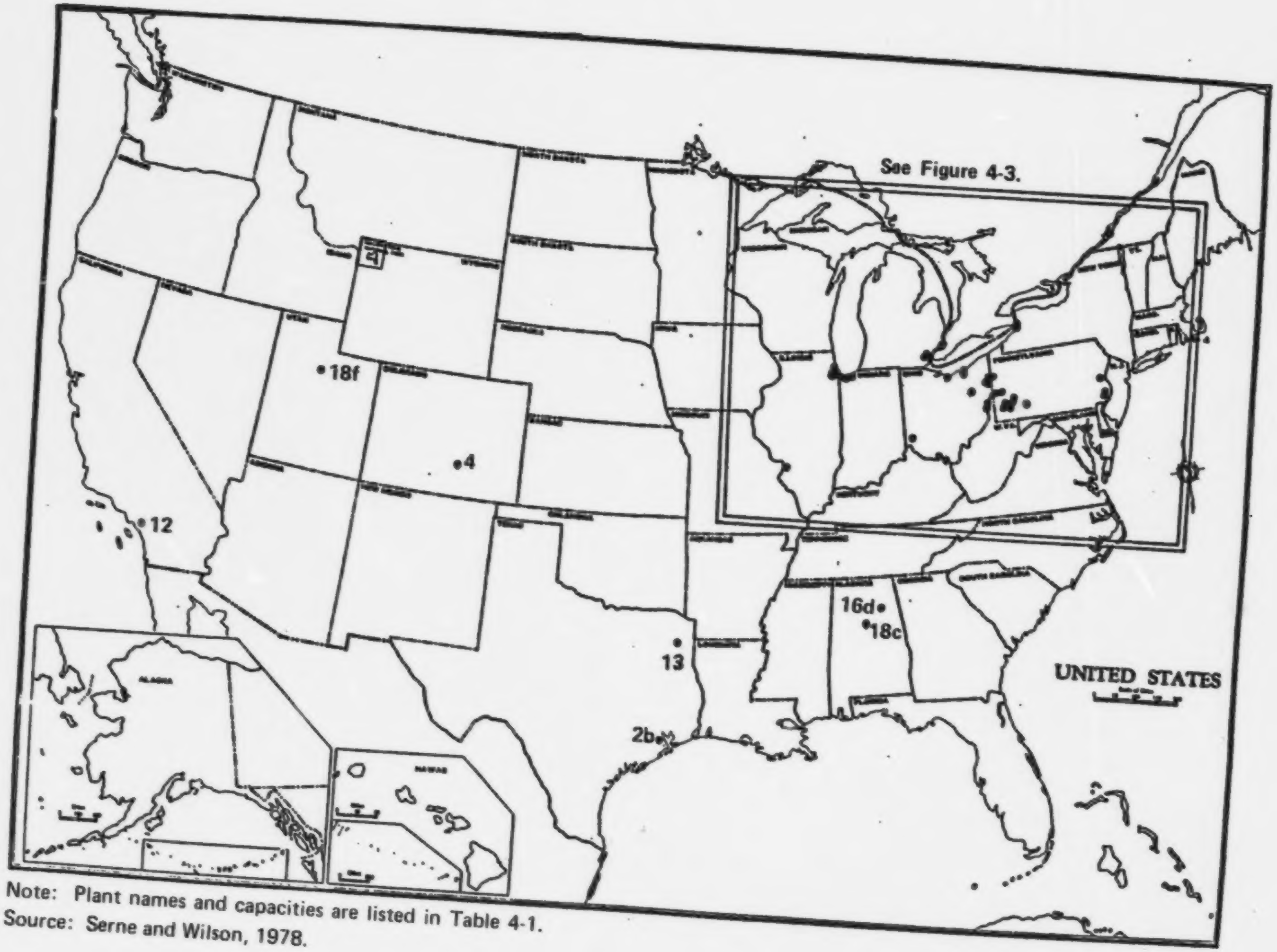
Figure 4-1. Annual steel production in the United States.

TABLE 4-1. USA-INTEGRATED STEEL COMPANIES AND PLANT CAPACITIES

Company		Plant location[a]	Raw steel capacity (net tons)
1. Alan Wood Steel Company		Conshohocken, PA	Shutdown
2. Armco Steel Corporation	a.	Ashland, KY	2,000,000
	b.	Houston, TX	1,500,000
	c.	Middletown, OH	3,800,000
3. Bethlehem Steel Corporation	a.	Bethlehem, PA	3,600,000
	b.	Burns Harbor, IN	4,500,000
	c.	Johnstown, PA	2,400,000
	d.	Lackawanna, NY	6,000,000
	e.	Sparrows Point, MD	7,500,000
4. CF&I Steel Corporation		Pueblo, CO	1,665,000
5. Crucible, Incorporated (Alloy Division)		Midland, PA	1,000,000
6. Cyclops Corporation		Portsmouth, OH	Shutdown
7. Ford Motor Company		Dearborn, MI	3,750,000
8. Inland Steel Company		East Chicago, IN	8,200,000
9. Interlake, Incorporated		Chicago, IL	900,000
10. International Harvester Company		South Chicago, IL	Shutdown
11. Jones and Laughlin Steel Corporation	a.	Aliquippa, PA	3,840,000
	b.	Cleveland, OH	3,100,000
	c.	Pittsburgh, PA	1,800,000
12. Kaiser Steel Corporation		Fontana, CA	4,000,000
13. Lone Star Steel Company		Lone Star, TX	1,500,000
14. McLouth Steel Corporation		Trenton, MI	3,400,000
15. National Steel Corporation	a.	Granite City, IL	2,500,000
	b.	Ecorse, MI	6,600,000
	c.	Weirton, WV	4,000,000
16. Republic Steel Corporation	a.	Buffalo, NY	1,000,000
	b.	Canton (Massilon), OH	1,500,000
	c.	Cleveland, OH	4,400,000
	d.	Gadsden, AL	1,500,000
	e.	South Chicago, IL	2,000,000
	f.	Warren (Youngstown), OH	2,700,000
17. Sharon Steel Corporation		Farrell, PA	1,900,000
18. United States Steel Corporation	a.	Braddock, PA	2,500,000
	b.	Duquesne, PA	3,000,000
	c.	Fairfield, AL	3,500,000
	d.	Fairless Hills, PA	4,400,000
	e.	Gary, IN	8,000,000
	f.	Geneva, UT	2,750,000
	g.	Homestead, PA	4,000,000
	h.	Lorain, OH	3,000,000
	i.	South Chicago, IL	5,250,000
	j.	Youngstown, OH	2,500,000
19. Wheeling-Pittsburgh Steel Corporation	a.	Monessen, PA	1,600,000
	b.	Steubenville, OH	2,800,000
20. Youngstown Sheet and Tube Company (Sold to Jones & Laughlin Steel Corporation)	a.	East Chicago, IN	5,500,000
	b.	Brier Hill (Youngstown), OH	Shutdown
	c.	Youngstown, OH	Shutdown
TOTAL			141,355,00

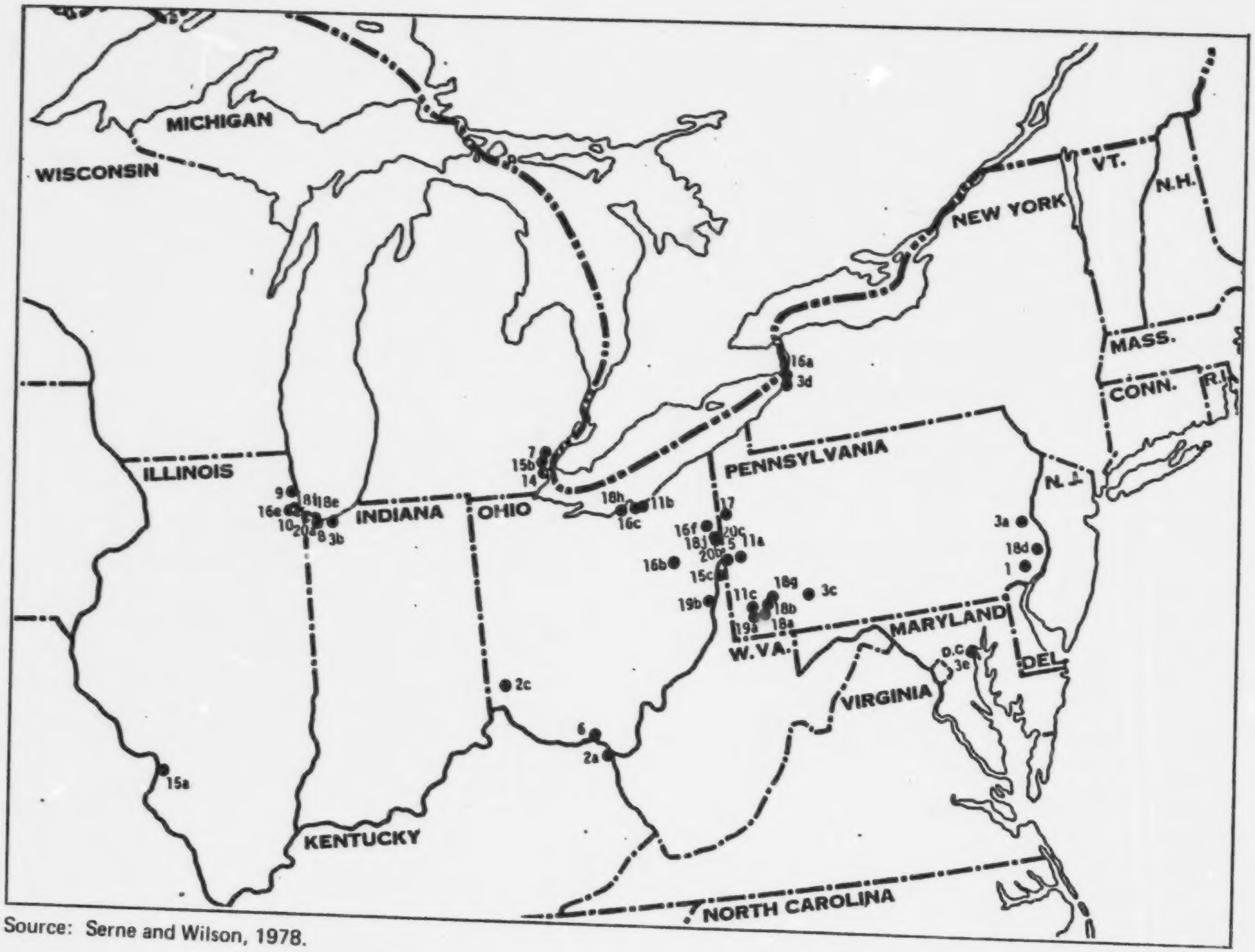
Source: Serne and Wilson, 1978.

[a] See Figures 4-2 and 4-3 for locations.


See Figure 4-3.
18f
4
12
13
2b
16d
18c
UNITED STATES

Note: Plant names and capacities are listed in Table 4-1.
Source: Serne and Wilson, 1978.

Figure 4-2. Integrated steel plant locations in the United States.


MICHIGAN
WISCONSIN
ILLINOIS
INDIANA
OHIO
KENTUCKY
PENNSYLVANIA
NEW YORK
VT.
N.H.
MASS.
CONN.
R.I.
N.J.
DEL.
MARYLAND
W.VA.
VIRGINIA
NORTH CAROLINA
D.C.
9
18i
18e
16e
10
20a
8
3b
15a
2c
6
2a
7
15b
14
18h
11b
16c
17
16f
20c
18j
5
11a
20b
16b
15c
19b
11c
18g
3c
18b
19a
18a
16a
3d
3a
18d
1
3e

Source: Serne and Wilson, 1978.

Figure 4-3. Integrated steel plant locations in the United States.

capacity. This total steel production capacity compares with the reported 1981 industry's raw steel production capability, i.e., the production capacity in service, of 154,300,000 tons (AISI, 1982).

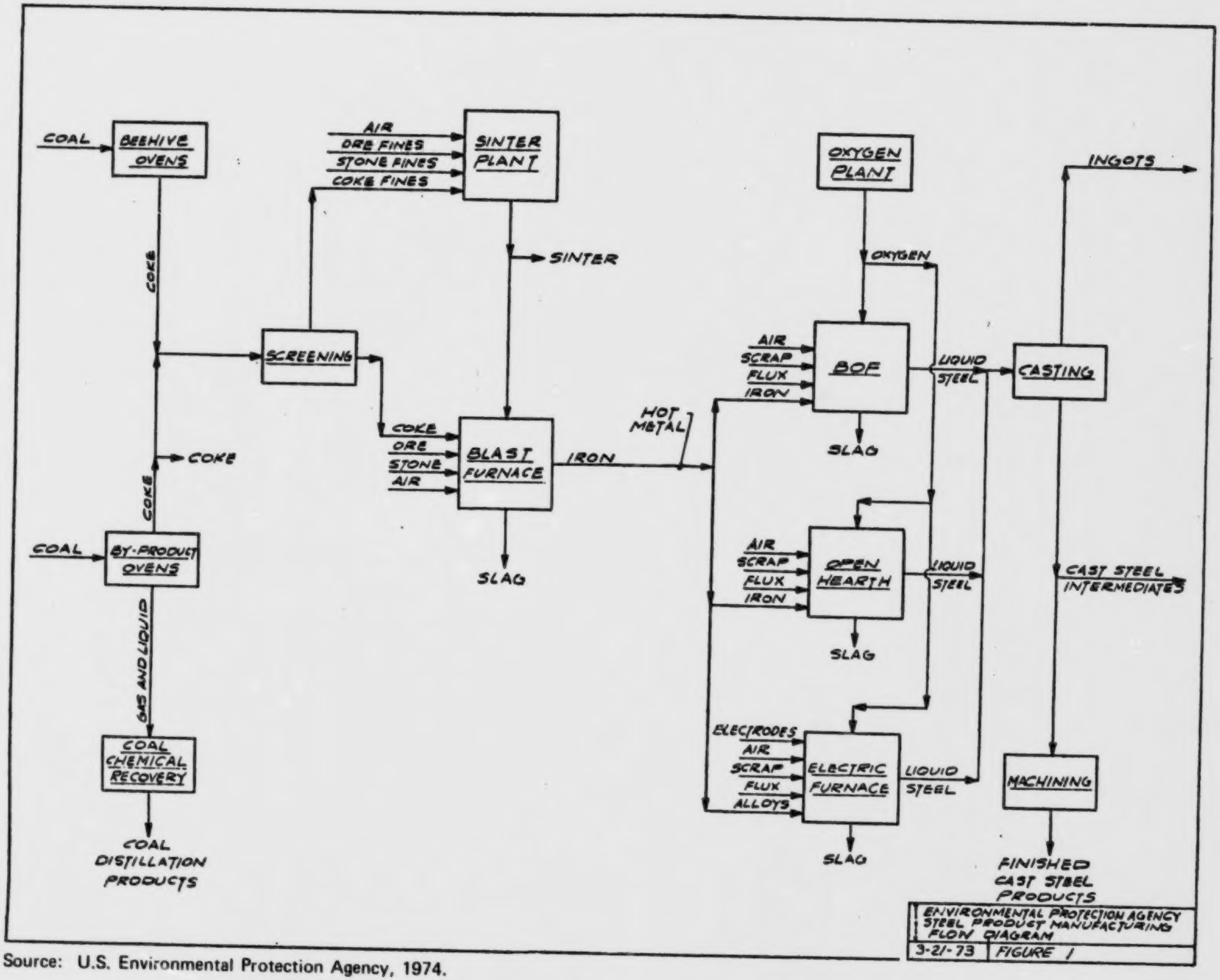
Figure 4-4 presents a block flow diagram of an integrated steel manufacturing plant showing major process operations. In a typical integrated steel plant, these operations include coke production from coal and recovery of coke by-product chemicals; the production of sinter from recycled wastes for blast furnace feed; the production of iron in blast furnaces; the production of steel from pig iron, molten iron, and metal scrap in basic oxygen, electric arc, and open hearth furnaces; ingot and continuous casting of molten steel; hot and cold rolling operations; and a variety of product finishing operations including scarfing, grinding, surface cleaning (pickling), and metallic coating (tin plating). Detailed descriptions of these operations may be found elsewhere (McGannon, 1971).

Since integrated steel plants represent about 85 percent of the iron and steel industry's production capacity and the operations and facilities of specialty and mini/midi steel plants vary quite widely, this study focused only on the integrated steel manufacturing plants.

4.2 ORGANIC MATERIAL INPUTS

On a macroscopic basis, organic material inputs for a typical integrated steel manufacturing operation may include the following:

- Coal
- Coke
- Fuel (gas, oil, tar, pitch, cresote, etc.)
- Raw material residuals (e.g., oil and lubricants on scrap metal)
- Oil and grease lubricants
- Coating oils


COAL
BEEHIVE OVENS
COKE
SCREENING
COKE
COAL
BY-PRODUCT OVENS
COKE
GAS AND LIQUID
COAL CHEMICAL RECOVERY
COAL DISTILLATION PRODUCTS
AIR
ORE FINES
STONE FINES
COKE FINES
SINTER PLANT
SINTER
COKE
ORE
STONE
AIR
BLAST FURNACE
SLAG
IRON
HOT METAL
OXYGEN PLANT
OXYGEN
AIR
SCRAP
FLUX
IRON
BOF
SLAG
LIQUID STEEL
AIR
SCRAP
FLUX
IRON
OPEN HEARTH
SLAG
LIQUID STEEL
ELECTRODES
AIR
SCRAP
FLUX
ALLOYS
ELECTRIC FURNACE
SLAG
LIQUID STEEL
CASTING
INGOTS
CAST STEEL INTERMEDIATES
MACHINING
FINISHED CAST STEEL PRODUCTS
ENVIRONMENTAL PROTECTION AGENCY STEEL PRODUCT MANUFACTURING FLOW DIAGRAM
3-21-73
FIGURE 1

Source: U.S. Environmental Protection Agency, 1974.

Figure 4-4. Integrated steel manufacturing plant flow diagram.

- Organic binders for pellets and agglomerates
- Carbon electrodes
- Water contaminants
- Finishing materials for products (e.g., paints and other organic coatings)

The absolute and relative quantities of the above organic materials and their point of use in the integrated steel plant may vary substantially from plant to plant. This variation depends on a number of factors including the plant size, equipment, and process operations; production rate; product type and mix; operation practices; and production cost considerations. For example, Pacific Environmental Services' study (Serne and Wilson, 1978) indicated that the iron and steel industry usage of lubricants, oils, greases, and hydraulic fluids, which represent a potentially significant source of organics pollution due to the large quantities used, can be reasonably correlated linearly with plant overall steel production capacity and rolling mill capacity. This study also showed that variations in operating practices associated with lubricating procedures and the use of rolling oils in hot rolling mill operations can have a significant impact on the consumption of oils and lubricants and the magnitude and source of attendant organic emissions.

In coke production, which is done in most integrated steel plants, coal is devolatilized (pyrolyzed in the absence of air) to form coke. This coke is used predominantly in the blast furnace ironmaking operations where it serves both as a reductant to convert the iron ore to metallic iron and as a fuel to supply part of the heat requirements of the process. It is also used in the steelmaking operatons as a source of carbon, a minor component of the steel, and as fuel. Coke fines are also mixed with sludge, dust, and mill scale in the sintering process to provide fuel in the production of sinter. Although coke is generally produced in the integrated steel plant, it is also listed as an organic material input because today significant percentages of the coke consumed in the intergrated steel plant are purchased from outside sources.

The raw material residuals are generally lubricating oils and greases, cutting and annealing oils, coating oils, and other organic protective coatings associated with scrap metal. These organic residuals enter the integrated steel plant in the ironmaking and steelmaking operations where they are vaporized, cracked, and partially burned in the furnaces. Mill operating practices in segregating clean and dirty scrap, the type of steelmaking furnace, and the source of scrap are the dominating factors affecting the amount of organic emissions in the steel plant from these residuals.

In addition to the coke and coke oven and blast furnace gases which are generated and consumed internally in the integrated steel plant, other fuels such as natural gas, coal, oils, tars, pitch, and creosote may be used. For example, in some operatons fuel oil or coal may be injected into the blast furnace along with the blast air to provide additional heat in the lower regions of the blast furnace (McGannon, 1971). The tars and pitches which may come either from outside sources or from the coke by-product chemical recovery operations may be used as fuel in open hearth furnace steelmaking (VanOsdell, et al., 1978a).

The carbon electrodes used in an electric arc furnace are another source of organic material introduced into the integrated steel plant; albeit, they probably represent a minor organic emission source. Although these electrodes are primarily graphitic carbon, they typically contain a significant amount of organic binder for the mechanical strength and structural integrity of the electrodes. In the electric arc furnace, organic species are generated in the plasma zone surrounding the electrodes through the vaporization and cracking of these pitch binders and through chemical reactions involving these binders and the graphitic carbon.

As mentioned previously, lubricating, rolling and coating oils; greases; and hydraulic fluids represent a major potential organic emission source in the iron and steel industry because of the large quantities used. Table 4-2 shows the annual consumption of lubricant, oil, grease, and hydraulic fluid for an integrated steel plant producing 3,277,000 tons of steel per year. This consumption corresponds to approximately 5.67 lbs. of lubricants per ton of steel produced. Of this lubricant consumed approximately 85 percent of it is used in a steel plant's rolling mill operations (Serne and Wilson, 1978). The fate of these lubricants, oils, greases, and hydraulic fluids in an integrated steel plant is summarized in Table 4-3. As indicated in Table 4-3, approximately 10 percent of these lubricating materials consumed or 0.590 lbs of lubricants per ton of steel produced is volatilized and enters the atmosphere.

Water contaminants (organics) were listed as an organic material input to the integrated steel plant because of the large quantities of water consumed and the geographical clustering of many integrated steel plants around common water sources, although this input probably represents a minor source of organic emissions. Within the steel plant, water is used for the conductive cooling of high temperature equipment, for direct contact evaporative cooling of slag and hot rolling mills, and for wet scrubbing air pollution control devices. Although integrated steel mills have water treatment facilities and are moving toward 100 percent water recycle (i.e., zero percent water effluent discharge), significant quantities of organic contaminants in the wastewater discharge from these steel plants find their way back into the common water source used by other steel plants. Therefore, since the prevailing practice in integrated steel plants is to use the cleanest water available in evaporative cooling operations (presumably makeup water from this water source) the organic contaminants in the water may be introduced into the atmosphere. This potential was not investigated in this study.

As part of the finishing operations in an integrated steel plant, coating oils and, in some cases, paints and other polymeric materials are applied to the surface of the steel products to provide corrosion protection in storage and handling. The application of these coating materials

TABLE 4-2. ANNUAL CONSUMPTION OF LUBRICANT, OIL, GREASE, AND HYDRAULIC FLUID IN A TYPICAL INTEGRATED STEEL PLANT

Department[a]	Consumption (ton/yr)
80" Hot strip mill	1,700.4
44" & 45" Blooming or slabbing mills	1,957.4
Continuous picklers	380.0
Tin plate mills including picklers	393.8
Rolling oil	2,475.0
Sheet mills including picklers	343.2
Rolling oil	875.0
Electrolytic washers	3.3
Electrolytic tin lines	8.0
Blast furnaces, BOF's, and auxiliaries	290.0
Seamless pipe mills	89.0
Threading oil	270.0
Buttweld pipe mills	91.0
Threading oil	180.0
Continuous galvanizing line	72.0
Coating oil	164.4
	9,292.4

[a] The annual steel production rate corresponding to these consumption data was 3,277,000 tons/yr.

TABLE 4-3. FATE OF LUBRICANTS, OILS, GREASES, AND HYDRAULIC FLUIDS IN A TYPICAL INTEGRATED STEEL PLANT[a]

Input term	Quantity (gal/yr)	Output term	Quantity (gal/yr)	Percent of input
Hydraulic oils	284,000	Drained, collected	250,500	46.9
Bulk grease	31,625[b]	In sludges[c]	57,800	10.8
Gear oils	115,000	Wastewater discharge[d]	57,300	10.7
Coating oils	58,000	Volatized	51,595	9.7
Rolling oils	31,000	On products	40,740	7.6
Miscellaneous greases	2,500	On mill scale[c]	36,800	6.9
Miscellaneous oils	7,000	Trash and debris	19,825	3.7
Motor oils	5,000	Leaks and spills	7,000	1.3
		Left in containers	1,382	0.3
Totals	534,125		519,342	97.9
		Unaccounted for	14,783	2.1

Source: Serne and Wilson, 1978.

[a] Steel production of 700,000 tons/year.

[b] Conversion factor of 8 lb/gal used to convert grease data to gallons.

[c] Lubricants in sludges and on mill scale may become air pollutants when recycled to sinter plant.

[d] Lubricants in wastewater discharge may enter atmosphere via evaporation.

as well as partial evaporation of these materials from the metal surface are sources of organic emissions to the atmosphere. The amount of these organic emissions, however, is dependent on steel plant production schedules and product specifications and mix; and, therefore, may not only be highly variable over time within a steel plant, but may also be quite variable between plants.

4.3 ORGANIC EMISSION SOURCES AND CONTROL

4.3.1 By-Product Cokemaking

Coke is one of the basic materials used in blast furnaces for the conversion of iron ore into iron. Coke also is used by a number of other industries, principally iron foundries, nonferrous smelters, ferroalloy plants and chemical plants.

Coke is produced predominantly in the by-product recovery or slot oven process. The conversion of coal to coke is performed in long, narrow slot ovens which are designed to permit separation and recovery of the volatile materials (by-products) evolved from coal during the coking process.

Coal is usually received on railroad cars or barges. Conveyor belts transfer the coal as needed from the barges or from a coal storage pile to mixing bins where the various types of coal are stored.

The coal is then crushed, mixed, and blended. The coal mixture is charged to the slot ovens through charge ports in the top of the ovens. Thermal distillation of coal to separate volatile and nonvolatile components takes place in coke ovens that are grouped in batteries.

The operation of each oven in the battery is cyclic, but the batteries usually contain a sufficiently large number of ovens (an average of 57) so that the yield of by-products is essentially continuous. The individual ovens are charged and discharged at approximately equal time intervals during the coking cycle.

After the ovens are filled, coking proceeds for 15 to 18 hr to produce blast furnace coke and 25 to 30 hr to produce foundry coke. The gases and hydrocarbons that are evolved during the thermal distillation are removed through the offtake main and sent to the by-product plant for recovery.

At the end of the coking cycle, doors at both ends of the oven are removed and the incandescent coke is pushed from the oven into a special railroad car, called a quench car. The quench car carries the coke to the end of the battery to a quench tower where it is deluged with water so that it will not continue to burn.

Coke is then crushed and screened to obtain the optimum size for blast furnace operations. The undersize coke generated by the crushing and screening operations is used in other steel plant processes, stockpiled, or sold.

Gases evolved during coking leave the coke oven through a gas collection main which directs them to the by-product plant. These gases account for 20 to 35 percent by weight of the initial coal charge and are composed of water vapor, tar, light oils, heavy hydrocarbons, and other chemical compounds. These gases are cleaned for use as fuel and to recover the contained tars, acids, naphthalene, ammonia, benzene, toluene, and xylene. A generalized by-product recovery process involves up to eight operations with some 42 pollutant sources.

The principle sources of organic compound emissions are leaks from coke battery doors, charging ports, and gas offtakes; charging operations; quench towers, especially when by-product waste water is used; and a multitude of fugitive losses from by-product recovery process equipment.

4.3.2 Blast Furnace Ironmaking (Jablin, et al., 1978)

The blast furnace converts iron oxide to molten iron. A typical burden (feed) comprises ore, sinter, limestone, and coke. The coke provides thermal energy for the process and a reductant gas for iron ore conversion, and serves as the pathway for passage of gases through the burden. The limestone becomes calcined, melts, reacts with and partially removes sulfur from the molten iron.

The burden material is charged into the top of the vertical shaft furnace and descends slowly. Heated air is injected through tuyeres near the bottom of the furnace. The air moves countercurrent to the burden, consuming the coke carbon thereby providing energy for the process. Blast furnace gas which leaves through offtakes at the top of the furnace is cleaned of particulates and used as a byproduct fuel. Molten iron and slag are tapped periodically from the bottom of the furnace.

Although ironmaking in the blast furnace is essentially a continuous process certain aspects of the blast furnace operation are not continuous. One is the periodic tapping. Usually 6 to 8 times per day, the hearth of the blast furnace becomes full of molten iron and slag. The tap hole (or holes) in the furnace wall is drilled. First, iron flows from the hole and travels to receiving ladles via iron runners. Finally, slag flows to slag ladles, to a cooling pit alongside the furnace, or to a special slag processing machine. After the flows of iron and slag cease, the tap hole is plugged with a special clay and the liquid iron and slag are allowed to accumulate in the hearth.

The other quasi-continuous operation is the process of filling the furnace with the burden material. Because the furnace is under pressure, an arrangement of pressure locks is provided. These locks, operating in sequence, permit the entry of the raw material and restrict the outward flow of the gas. Typically, the locks are in the form of two inverted cones called bells, one above the other, the top bell being considerably the smaller of the two. Operation consists of placing the material on the top bell, opening it to dump material to the bottom bell, and repeating the action until the bottom bell is full of material. When this occurs, the top bell is closed, the bottom bell is opened and the material passes into the furnace. Gas flow is impeded by virtue of only one bell being open at a time.

Organics may be introduced to the process via materials charged to the furnace such as metal turnings, coke, or alternate fuels (fuel oil, coal) used to supplement furnace energy input. Organics may be released to the atmosphere through the opening of the small bell to accept a new charge or through leaks in the bell seals. Contact between the molten iron and clay used to line casthouse runners (containing organic binders) may also release organics.

4.3.3 The Sintering Process (Carpenter, et al., 1978)

The primary function of sintering is to agglomerate dusts and sludges from pollution control sources and fine ores into lumps suitable for charging into the blast furnace. The secondary function of sintering is to calcine part or all of the flux material for the ironmaking process.

The primary function stems from the need to provide physical mass, size, porosity, and strength to the material. Fine particles, if charged into the blast furnace, will be blown out by the rapid countercurrent flow of the furnace gases and will plug the burden, restricting the upward flow of gases. Lumps, being physically larger, will not be so affected.

The secondary function stems from the economics of the ironmaking process. A blast furnace operates more economically if the flux is precalcined, that is, if lime (CaO) is charged rather than limestone ($CaCo_3$). It is, however, too expensive to substitute purchased lime for limestone in the blast furnace. The preferred course is to mix limestone in the sinter feed and use the heat of the sintering process for calcining it.

The sintering process includes receiving, mixing, feeding, and agglomerating the raw materials; the actual sintering operation; and the crushing, screening, cooling, and transferring of the sinter product.

Feed material to the sintering process includes primarily ore fines, reverts (blast furnace dust, mill scale, and other by-products of steelmaking), recycled hot and cold fines from the sintering process, and trim materials (calcite fines, and other supplemental materials needed to produce a sinter product with prescribed chemistry and tonnage).

Organic vapor emissions at a sinter plant generally originate from oil in the feed material. Some sources of oil-bearing feed are:

1. Mill scale which absorbs oil that finds its way into mill water from leaky bearings, hydraulic equipment, etc.
2. Blast furnace sludge which absorbs oil that finds its way into blast furnace scrubber water from the blast furnace process itself.
3. Coke breeze which may contain tarry material and which absorbs oil from the water in the sump of the quench tower.

If the oil-bearing feed material is not uniformly distributed through the total feed burden, there may be occasions where the concentration of these materials becomes much higher than normal. Under such conditions, the concentration of organic vapors in the stack may be expected to increase. The oil present in the feed material appears to be vaporized on the strand ahead of the flame front and may be pyrolyzed and/or partially burned.

4.3.4 Basic Oxygen Process Steelmaking (Coy, et al., 1978)

The basic oxygen process (BOP) furnace receives a charge composed of molten iron and scrap and converts it to molten steel. A jet of high purity oxygen oxidizes the carbon and the silicon in the molten iron to remove these elements and to provide heat for melting the scrap. After the oxygen jet is started, lime, usually in the form of pebble lime, is added to the top of the bath to provide a slag of the desired basicity. Fluorspar and mill scale are also added to achieve the desired slag fluidity.

The basic oxygen steelmaking process is essentially a thermochemical process which lends itself, more or less, to the application of computer control. The process starts with the analysis of the composition of the molten iron and its temperature. These data are applied to the desired chemistry of the finished product and computations are made which determine the percentage of molten iron, the percentage of scrap, the amount of flux materials and the amount of alloy additions. If all goes exactly as planned, after the injection of the precalculated amount of oxygen, the vessel is turned down; a steel analysis is made; and the heat is tapped. If the heat is off analysis, it may be necessary either to blow with additional oxygen to elevate temperature or cool the steel by coolant additions to the bath. Alloy addition may also be required.

The principal components of the charge are molten iron and scrap. Scrap is received in the shop by means of railroad gondola cars. Molten iron is usually brought to the shop by means of railroad ladle (torpedo) cars and is transferred to the shop ladle at the ladle transfer station. When the vessel is ready for charging, it is tilted toward the charging aisle and the scrap box lifted and dumped into the vessel. Next, the ladle of molten iron is poured into the vessel over the scrap. The vessel is turned upright, the oxygen lance lowered, and the blow commences. Immediately after the start of the blow, lime and fluorspar in the desired quantities are fed through the chute into the vessel from the weigh hopper.

In addition to the oxygen lance type of BOP furnace, a bottom-blown type of BOP furnace (Q-BOP) is used, albeit on a more limited basis than the lance-type furnace, for steelmaking. The Q-BOP process is carried out in a basic lined vessel that is fitted with bottom tuyeres through which gas flows continuously (even during charging operations) so that the tuyeres do not become blocked.

During steel making oxygen and natural gas are injected into the furnace through the tuyeres. When the Q-BOP vessel is tilted for charging or for taking a molten steel sample, the oxygen and natural gas flows are stopped and are replaced by a flow of nitrogen. In any event, there is a copious flow of emissions from the mouth of the vessel due to the gas flow from the tuyeres. Two large, horizontally sliding doors assist in directing the gases back into the collection system and protect workers who are on the charging floor. These doors are opened only to permit the addition of scrap and molten iron and are closed at all other times.

When the heat is complete, the vessel is tilted and the steel is poured into the steel ladle. The steel ladle is used to fill molds (ingots), or a continuous casting machine for the production of continuously cast product. After the steel is out of the vessel, slag is poured into a ladle or slag pots. Slag is generally carried away for processing in a remote site.

Organics enter BOP steelmaking principly through scrap charged to the furnace. Scrap purchased from sources outside the plant is a major contributor. Automobile and appliance scrap contains grease and oil that is volatilized and partially combusted as molten iron is poured into the furnace on top of the scrap.

4.3.5 Electric Arc Furnace Steelmaking (VanOsdell, et al., 1978b)

Electric arc furnaces produce steel from a charge of scrap iron and steel although molten iron may also be included. There are two advantages of electric arc furnace steelmaking. First, steel can be made directly from scrap without having a source of molten iron; i.e., blast furnace and coke ovens. Second, good control can be exercised over the quality of steel produced, making EAF's well suited for stainless steel and high alloy steel production. Economic constraints tend to favor the use of EAF's for low to medium tonnage steelmaking facilities.

The production of steel in an EAF is a batch operation consisting of several functional elements which must be performed sequentially. The production cycle typically requires 1½ to 5 hours for carbon steel, and 5 to 10 hours for high alloy steel. During charging, scrap iron and steel are loaded into the furnace. In a few plants, molten iron or direct reduced iron pellets may be used in addition to, or instead of, scrap. A meltdown period follows charging of scrap. As a pool of molten iron forms in the furnace oxidation reactions begin to remove carbon from the metal. The oxidation is expedited in some plants by the use of high purity oxygen injected through oxygen lances. Refining occurs as sulfur and phosphorous in the iron react with slagging agents, silica and lime. When the metal composition reaches the desired constituent levels the steel is poured into a ladle for transfer to ingot molds or a continuous caster. Slag is poured into a slag ladle or onto the floor below the furnace for subsequent removal and processing.

Scrap metal is a principle point of entry for organic materials into the process. Grease, oil, paint, and plastics contaminate automotive scrap, a major scrap source. Emissions of volatilized and partially combusted organic compounds are produced during charging.

Electrodes used in EAF's are made from carbonaceous materials and may contribute to organic compound formation. Organic compound formation may occur particularly under the reducing furnace conditions accompanying the double slag process for high alloy steels production.

4.3.6 Open Hearth Furnace Steelmaking (VanOsdell, et al., 1978a)

The open hearth furnace is a long-established process of making steel which originated in the 19th century. Present day open hearth furnaces are essentially the same in general form and concept to the original furnaces except that they are larger in capacity and better instrumented and controlled.

The open hearth furnace, however, is being phased out of production and is being replaced with the basic oxygen process which is more automated and requires less skilled operating manpower. Since 1967 domestic steel production in open hearth furnaces has decreased from 55.6 percent of total steel production to 11.1 percent in 1981. A previous EPA study (Weant and Overcash, 1977) projects that open hearth furnace tonnage will drop to only a few percent in the 1980's.

Unlike the basic oxygen processes, open hearth furnace shops were built before the advent of today's environmental regulations. The original designs did not provide for control of emissions. Such controls as have been provided in later years are all retrofits. As is usually the case with retrofitting a facility, its design and operation are compromises, and performance is often less than optimal. There is also a reluctance on the part of the steel companies to invest monies for environmental control on facilities such as the open hearth furnace which have a limited life. In fact, in many shops the need to provide such environmental control is the final impetus driving the company to replace the open hearth with the basic oxygen process and, in some cases, with the electric arc furnace.

Although the open hearth furnace is being phased out of production, it was included in this study because it stills provides a significant percentage of steel production capacity and is a significant source of organic emissions in steelmaking operations.

In open hearth furnace steel production, which is simple in concept, the raw materials (scrap steel, molten iron, and fluxes) are placed in a large rectangular refractory line chamber where the charge is heated with burners and refined with blown oxygen until the steel is of the desired composition where upon the product steel is drawn off into a ladle. After the disposal of the slag, a new cycle is initiated.

The generation of organic emissions in open hearth steelmaking operations stems from the combustion of fuel oil, tar, pitch, creosote and other similar organic materials to provide heat for the process and from the organic residuals on the scrap metal used. Because the fuels used in open hearth furnaces have combustion characteristics that may not lead to complete combustion in the furnace and because the metal scrap, containing residuals organics, is charged into the furnace at the beginning of the cycle where these organics may be volatilized during heatup of the scrap, substantial organic emisssions may occur. Moreover, because electrostatic precipitators for particulate emissions control are the most common pollution control device on an open hearth furnace, organic vapor emissions go virtually uncontrolled.

4.3.7 Hot Forming, Cold Rolling, and Finishing

If steel is teemed into ingots, it is brought to the desired primary hot rolling temperature in a soaking pit furnace. After soaking, the steel is sent to primary hot rolling, then stockpiled or rolled directly in the finishing mill. If it is stocked, it is reheated before secondary hot rolling. Reheating furnaces are fired with coke oven gas, natural gas and heavy oil in integrated steel mills. Between the two hot forming processes, the metal must be "conditioned." The surface usually has flaws and cracks that are removed. This is commonly done by scarfing (oxygen torch) which removes approximately a 3/16-inch layer of the surface on both sides of the slab.

Continuous casting is more efficient than ingot casting and yields 94 percent usable metal compared to 80 percent in the case of ingot casting. If steel is to be continuously cast, it is delivered directly to the caster in molten condition from the BOF or EAF. The molten metal pours through nozzles into an oscillating water cooled copper mold, where partial solidification takes place. The copper molds oscillate to prevent the molten steel from sticking to the sides of the molds. Lubricants, such as rape seed oil, are sprayed into the molds to facilitate steel movement through the mold. As the metal solidifies in the mold, the cast product is withdrawn continuously. After passing into a secondary cooling zone, where sprays of water remove sufficient heat to complete solidification of the semi-finished product, the product then passes into the cut-off zone, where it is cut to the desired length. It is then placed on the run-out conveyor tables for transport to storage facilities.

The semi-finished steel products -- slabs, blooms, and billets --are further processed on different types of secondary hot mills to form the desired finished product shapes. These secondary hot rolling mills include: bar, rail, section, structural, plate, sheet, and strip mills. Their function is to reduce the cross section of the semi-finished steel forms and to form specific cross-sectional shapes such as rails, I-beams, and other structural steel shapes.

In both the primary and secondary hot rolling mills water and water soluble oil are sprayed on the mill rolls and the steel being rolled for roll cooling and steel cleaning (scale removal) and lubrication. Part of the oil and water in these sprays is evaporated in the mill area. Also, some finished steel products from the secondary hot mills such as rails and rail joints are quenched in oil baths to control the steel's physical and mechanical properties.

The steel must be cleaned by an acid pickling dip before cold rolling. The metal is then cleaned with alkaline rinses if it is to be finished further. Cold rolling is the process in which flat unheated steel products are reduced in thickness by rolling operations. The rolling operation compresses the steel between rolls to reduce the thickness of the product while imparting desired physical, mechanical and surface properties. Oil solutions are applied directly to the rolls or product to dissipate the heat produced during rolling and to provide lubrication. Various oils and oil application systems are used depending on the product being rolled and the properties desired in the steel.

The cold rolled steel is often finished by dipping into molten zinc or aluminum or by applying zinc, tin, or chrome by electroplating. Finishing may include the application of surfacing techniques, e.g., painting, nitriding, welding.

4.4 EMISSION FACTORS AND POLLUTION CONTROL

Organic emission factors for point sources within the iron and steel industry are presented in Table 4-4. Also included in this table are estimates of total organic emissions by source for the iron and steel industry based on 1981 production data. With the exception of major studies on organic emissions from by-product cokemaking (RTI, 1982) and on the fate of lubricants in integrated steel plants, particularly hot forming and rolling mill operations (Mackus and Joshi, 1981), and several more modest studies such as RTI's study of organic emissions from basic oxygen process (Westbrook, 1979), there has been little work devoted to organic emissions from the other potential sources identified. Moreover, in the studies just identified, the motivation for the studies was primarily the identification of carcinogenic polynuclear aromatics rather than total organic compounds. Therefore, the general reliability rating of the emission factors for the iron and steel industry presented in Table 4-4 is rather low. Several of the values reported are estimates obtained from engineering analysis and partial or incomplete field emission data.

From Table 4-4, by-product cokemaking, as expected, appears to be the iron and steel industry's major organic emission source, accounting for approximately 50.7 percent of the organic emissions; followed by blast furnace ironmaking, accounting for about 16.8 percent of the organic emissions; sintering plant operations for 16 percent; electric arc furnace steelmaking for 13.7 percent; mill finishing operations for 2.5 percent; and basic oxygen process and open hearth furnace steelmaking combined contributing less than 0.5 percent to overall organic emissions. The magnitude of the by-product cokemaking emissions which is based on 1981 domestic coke production rather than total coke consumption is lower than would be the case if full domestic cokemaking capacity had been used to supply 100 percent of the iron and steel industry's coke requirements. Based on 1981 coke consumption data, annual organic emissions from cokemaking in the United States would have been approximately 7 percent higher than the figure reported in Table 4-4.

TABLE 4-4. ORGANIC EMISSIONS FROM POINT SOURCES WITHIN THE IRON AND STEEL INDUSTRY

Emission source	Organic emission factor[a] (lb/ton)	Organic emission factor[a] (kg/MT)	EF Rating	U.S. annual production (1981)[b] (tons)	Organic emissions (tons)	References
Byproduct Cokemaking						
Coal preheaters[c]	0.32	0.16	-	3,998,000	640	Sutherlant et al., 1980
Coke batteries	4.50[d]	2.25	C	38,117,000	85,763	RTI, 1981
Coke quenching	0.15[e]	0.075	C	~	2,954	Laube, 1979
Coke byproduct plant	6.86	3.43	C	~	130,741	RTI, 1982
Blast Furnace Ironmaking						
Furnace charging (bell opening)	0.19[f]	0.099	D	73,570,000	7,247	Appendix A
Bell leaks	0.241	0.121	D	~	8,865	Appendix A
Fugitive	1.54	0.77	D	~	56,649	Appendix B
Sintering Plant	4.80[e,g]	2.40	C	28,956,000	69,494	Carpenter et al., 1978
Basic Oxygen Furnace Steelmaking						
BOF (hot melt charging)	0.00116[h]	0.00068	C	69,002,000	40	Westbrook, 1980
Q-BOP (hot melt charging)	0.0244	0.0122	C	4,229,000	52	Westbrook, 1979
Electric Arc Furnace Steelmaking						
Charging, melting, and tapping	0.348[h]	0.174	C	34,145,000	59,413	Baldwin, 1982
Open Hearth Furnace						
Charging, melting, and tapping	0.168[h]	0.084	-	13,452,000	1,130	Estimated
Mill Finishing Operations						
Cold strip reduction mills	0.562[i]	0.281	D	29,360,000	8,250	Mackus and Joshi, 1981
Hot strip mills (50% use rolling oil)	0.081	0.041	D	70,994,000	2,875	Mackus and Joshi, 1981
Total					434,104	

[a] Emissions expressed per ton or metric ton of process unit/operation product output.

[b] 1981 steel production 120,828,000 tons (AISI, 1982).

[c] Negligible relative to total organic emissions because <10 coal preheaters in use. EF based on scrubber outlet data which indicated higher organic emissions than EF based on scrubber inlet data.

[d] Emissions per ton or metric ton of coke produced.

[e] Organic emissions expressed as CH_4.

[f] Emissions per ton or metric ton of molten iron produced.

[g] Emissions per ton or metric ton of sinter product.

[h] Emissions per ton or metric ton of steel produced.

[i] Emissions per ton or metric ton of finished steel.

In dry-coal charging cokemaking operations, coal preheaters are used to dry the coal before it is delivered to the charging bins from which pipelines, larry cars, or conveyors carry the coal to the individual coke ovens. These coal preheaters which operate at temperatures approaching 300°F vaporize some of the lower molecular weight organic volatiles in the coal. These vaporized organics leave the coal preheater in the gas stream carrying the dried coal to the cyclone separators that recover the coal for the charging bins. After these cyclones, this carrier gas is sent to a water scrubber to remove the coal particulate not removed in the cyclones before it is vented to the atmosphere. Some of the organics in this carrier gas, particularly the polar organics, are removed in the water scrubber.

One study (Sutherland et al., 1980) suggests, however, that the organics in this carrier gas leaving the scrubber may actually increase if scrubber water containing low molecular weight organics is used. This increase may occur because the hot carrier gas raises the scrubber water temperature thereby reducing the solubility of the organics in the organics contaminated water. The 0.32 lb/ton coal emission factor for coal preheaters reported in Table 4-4 is based on the gas leaving the scrubber. The emission factor based on scrubber gas inlet data is 0.11 lb/ton coal. These emission factors represent averages of multiple samples from one coal preheater facility.

There are 11 dry coal charged coke plants in the United States with a total annual capacity of 7,752,000 tons (RTI, 1980). Nine of these plants, representing 6,132,000 tons/year of cokemaking capacity, are part of integrated iron and steel plants. The total dry and wet coal charged coke plant capacity of integrated iron and steel plants is approximately 58,475,000 tons/year (RTI, 1982). In Table 4-4, the 1981 coke production in dry coal charged coke plants was assumed equal to the relative annual capacity of these plants, i.e., 10.49 percent of total iron and steel industry coke production.

Of the emission factors for the iron and steel industry presented in Table 4-4 those reported for blast furnace ironmaking operations are least reliable because they were derived from engineering estimates. Nevertheless, these blast furnace organic emission factor estimates, which we believe are reasonable and conservative, indicate that blast furnace ironmaking is potentially the second largest source of organic emissions in the iron an steel industry. Therefore, this situation suggests that blast furnace ironmaking operations is an area requiring future study of organic emissions.

To develop an overall organic emission factor and to establish the magnitude of organic emissions that might be representative of a typical integrated steel plant operation, a typical (hypothetical) integrated steel plant was established. The average size of the integrated steel mill was taken to be 3 million tons per year of finished steel (Serne and Wilson, 1978). Since there are differences in design, equipment, and operating practices between integrated steel plants, it was assumed that the typical or hypothetical integrated steel plant reflected iron and steel industry-wide operations in terms of equipment, production configurations, and relative production rates for the various processing operations. Also, it was assumed that this typical integrated steel plant was self-sufficient, that is, coke, sinter, and iron production exactly match the requirements for steel production. The basic assumptions used for this hypothetical integrated steel plant are embodied in Figure 4-5. The organic emissions and emission factors (expressed per ton of steel produced) for the identified emission sources in this hypothetical steel plant are presented in Table 4-5.

In a comparison of the tabulated organic emissions in Tables 4-4 and 4-5, there is a difference in the ranking of the emission sources in terms of their relative contributions to total organic emissions. This difference is an artifact related to the different bases used in preparing the tables. Table 4-4 is based on published 1981 production statistics for the iron and steel industry in which the production rates for coke and sinter used in

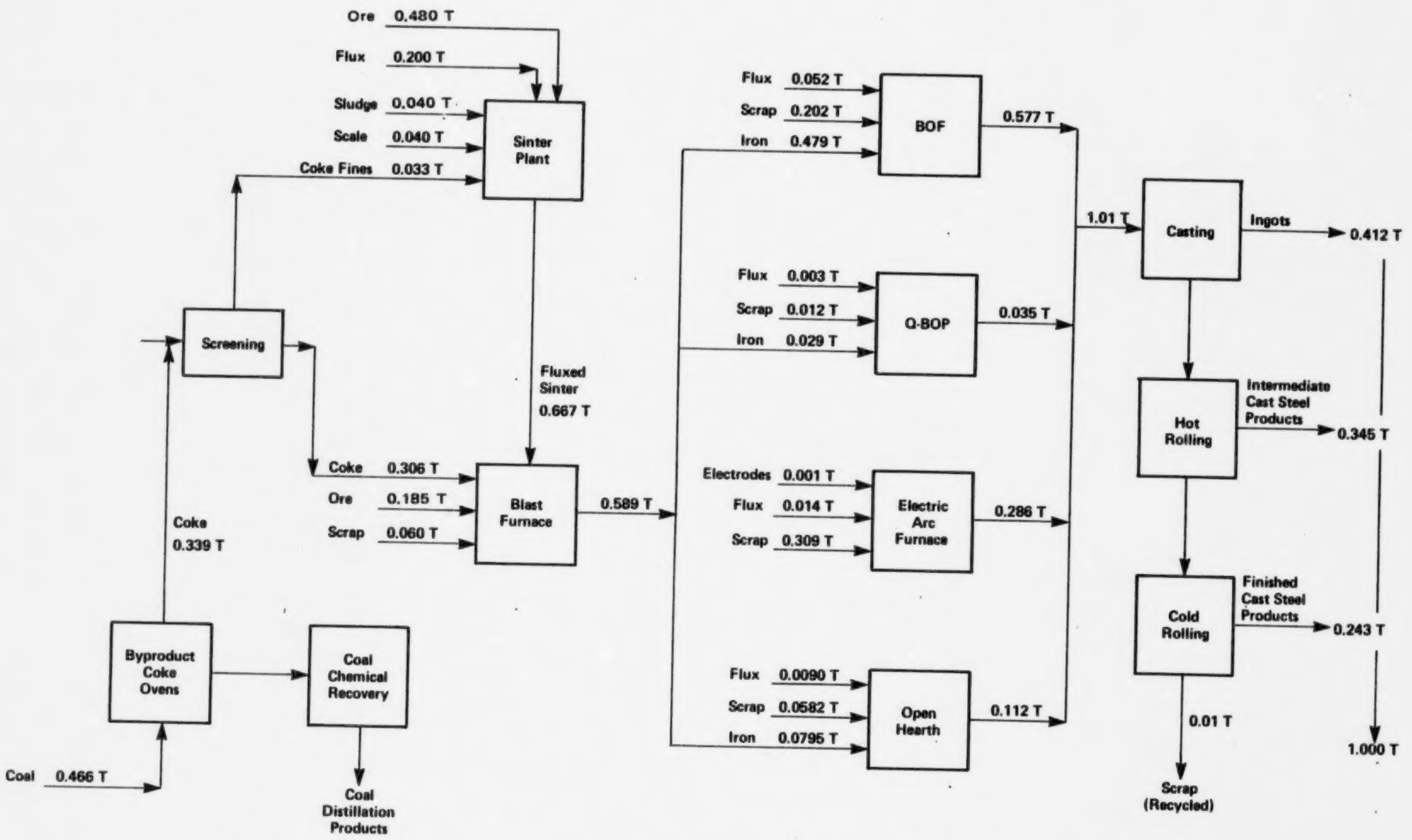

Ore 0.480 T
Flux 0.200 T
Sludge 0.040 T
Scale 0.040 T
Coke Fines 0.033 T
Sinter Plant
Screening
Fluxed Sinter 0.667 T
Coke 0.306 T
Ore 0.185 T
Scrap 0.060 T
Blast Furnace
0.589 T
Coke 0.339 T
Byproduct Coke Ovens
Coal Chemical Recovery
Coal Distillation Products
Coal 0.466 T
Flux 0.052 T
Scrap 0.202 T
Iron 0.479 T
BOF
0.577 T
Flux 0.003 T
Scrap 0.012 T
Iron 0.029 T
Q-BOP
0.035 T
Electrodes 0.001 T
Flux 0.014 T
Scrap 0.309 T
Electric Arc Furnace
0.286 T
Flux 0.0090 T
Scrap 0.0582 T
Iron 0.0795 T
Open Hearth
0.112 T
1.01 T
Casting
Ingots
0.412 T
Hot Rolling
Intermediate Cast Steel Products
0.345 T
Cold Rolling
Finished Cast Steel Products
0.243 T
0.01 T
Scrap (Recycled)
1.000 T

Figure 4-5. Production requirements to manufacture 1.0 ton of steel products in a hypothetical integrated steel plant.

TABLE 4-5. ORGANIC EMISSIONS FOR A TYPICAL INTEGRATED STEEL PLANT PRODUCING 3,000,000 TONS OF FINISHED STEEL/YEAR

Emission source	Emission factor (lb/ton product)	Emission factor (lb/ton finished steel)	Operation production capacity (ton product/yr)	Organic emissions (ton/yr)	Source contribution (percent of total emissions)
Byproduct cokemaking	11.55[a]	3.92	1,017,000	5,873.2	45.59
Blast furnace ironmaking	1.978[b]	1.17	1,770,000	1,750.5	13.59
Sinter plant	4.80[c]	3.20	2,001,000	4,802.4	37.28
Basic oxygen process steelmaking					
BOF	0.0016[d]	0.00093	1,731,000	1.4	0.01
Q-BOP	0.0244[d]	0.00087	105,000	1.3	0.01
Electric arc furnace steelmaking	0.348[d]	0.0995	858,000	149.3	1.16
Open hearth furnace steelmaking	0.168[d]	0.0188	336,000	28.2	0.22
Mill finishing operations					
Cold strip reduction mills	0.562[e]	0.137	729,000	204.8	1.59
Hot strip mills	0.081[e]	0.0476	1,764,000	71.4	0.55
Totals	-	8.59	-	12,882.5	100.00

[a] Coke product.

[b] Iron product.

[c] Sinter product.

[d] Steel product.

[e] Finished steel product.

Note

1.0 lb/ton = 0.5 kg/MT

1.0 ton = 0.9072 MT (metric ton)

1.0 MT = 1,000 kg = 1.0 Mg

the calculations reflect only the amount of these materials produced within the steel plant and does not include outside purchases required to supplement in-plant production for steel manufacturing. Also, the production rate for iron used in Table 4-4 includes the amount of iron produced in excess of that required for in-plant steel manufacturing. Therefore, Table 4-4 estimates the actual organic emissions attributable to the iron and steel industry for 1981.

Because of either extra-plant purchases of short-fall produced intermediates (i.e., coke, sinter) or sales of over-produced intermediates (i.e., iron) required for steel production, these organic emission quantities do not necessarily reflect the emission quantities associated in the production of finished steel from the basic raw materials of coal, iron ore, and scrap metal. Moreover, since the purchases and sales of steel manufacturing intermediates such as coke, sinter, and pig iron are stochastically variable from year to year, the relative contributions of the various organic emissions sources within the steel plant as shown in Table 4-4 may be different for each production year.

In Table 4-5, however, it is assumed that the in-plant production of steel manufacturing intermediates exactly matched the requirements for steelmaking. Therefore, the emission factors normalized on a per ton of steel produced basis and the organic emission quantities shown in Table 4-5 more acurately portray the organic emissions associated with the steelmaking process itself. Whereas, organic emission quantities in Table 4-4 are somewhat distorted by iron and steel industry economic considerations and constraints. Based on the normalized emission factors from Table 4-5 and 1981 annual steel production of 120,828,000 tons, the estimated total organic emission is approximately 518,956 tons or approximately 20 percent higher than the emission based on actual production statistics as shown in Table 4-4.

From Table 4-5, the three largest and by far the most significant organic emission sources, representing over 96 percent of the organic emissions, are in order of decreasing contribution by-product cokemaking, sinter production, and blast furnace ironmaking.

The major contribution of by-product cokemaking to organic emissions in the iron and steel industry has long been recognized. EPA has sponsored a number of studies (RTI, 1982) for the establishment of background data on cokemaking, pursuant to the development of regulatory standards.

In brief, control of coke battery charging emissions is achieved by stage charging combined with work practices. Door leaks are prevented by improved door seals and jambs combined with special work and maintenance practices. Charging lid leaks are prevented by luting, and offtake leaks by luting and maintenance practices. For by-product plants, the most effective control technology is the use of gas blanketing with venting of potential emissions to the collection main of coke oven gas distribution system. This technology provides for recovery of the organics either as by-products or for their fuel value. Model plant cost estimates for the gas blanketing and venting control technology suggest potential annual operating credits for the by-product plants due to credits for recovered benzene and other organic compounds.

In sinter plants, the pollution control devices in use which include electrostatic precipitators, scrubbers, cyclones, and fabric filters are designed primarily for particulate emissions control. High pressure drop venturi scrubbers have been applied to eliminate visible hydrocarbon plumes from windbox stacks, but data on the control efficiency for organic emissions are not available. Wet electrostatic precipitators (WESP) have also been suggested to control visible hydrocarbons plumes from windbox waste gas streams. Data from a demonstration WESP applied to the Bethlehem Steel Johnstown sinter plant show some reduction in chloroform extractable hydrocarbons for baseline plant operating conditions (Jaasund and Mazer, 1977). However, in further tests at the same plant conducted while producing high basicity sinter, chloroform extractable hydrocarbon concentrations were higher at the outlet than the inlet. Tests at National Steel's Weirton

Sinter Plant investigated the use of windbox recirculation and granular bed filters for particulate and organic emission control (Current, 1979). Although a 32 percent reduction in organics emissions with 25 percent wind box recirculation was reported, this result must be used with caution because of organics sampling and analysis problems. The reduction of organic emissions from sinter plant windbox gas Weirton windbox study and RTI Level 1 analysis streams via downstream control devices has not been clearly demonstrated over a wide range of operating conditions.

Although some removal of organic emissions may be obtained with these particulate control devices, operating procedures are most widely used in an effort to control organic emissions from sintering operations. For example, limiting the proportion of oily material in the sinter process feed (i.e., mill scale less than 20 percent and filter cake less than 5 percent) and using only mill scale with low oil content are the primary methods currently being used to reduce organic emissions from sinter plants (Carpenter, et al., 1978).

Control of oily material feed to the sinter plant potentially may have a significant impact on organic emissions since up to 72 percent (Serne and Wilson, 1978) of oily material entering the plant is volatilized and escapes unburned. The extent of organics destruction in the sinter plant, however, is quite variable depending on operating conditions and amount of organics in the burden. Reported estimates of organics destruction include 28% (Serne and Wilson, 1978), 84% (Westbrook, 1979), and 95% (Current, 1979).

There is a limitation, however, to the reduction in oily material charge obtainable because these oily materials are associated with steel plant solid waste such as coke fines, dusts, mill scale, and sludge that are recycled to the sinter plant as one of the primary means of controlling solid wastes. Therefore, restricting the charge of oily materials by eliminating mill scale and sludge from sinter plant feed would adversely impact solid waste disposal, thereby, trading off atmospheric emissions for solid waste pollution.

As a result of current practices in emission control in sinter plants and in view of this study, it appears that the sintering process requires further study regarding organic emissions and control.

Heretofore, the blast furnace ironmaking operation generally had not been considered a major source of organic emissions because top gases are first cleaned in wet scrubbers to remove particulates and then burned as fuel. Top side emissions of blast furnace gas due to leakage around bell seals and the opening and closing of the bells during burden charging and fugitive emissions from the piping used to distribute the blast furnace gas throughout the steel plant, however, appear to be potentially significant sources of organic emissions. Virtually, no investigation of organic emissions from blast furnace operations has been undertaken; the emission factors recorded in this study were calculated on the basis of engineering analysis. It would therefore be appropriate to investigate more closely organic emissions from blast furnace ironmaking. An initial approach might be a qualitative analysis of blast furnace off-gas to identify organic species and to make preliminary estimates of their concentration.

In steelmaking operations, the electric arc furnace appears to be the major source of organic emissions although this source of emissions is much smaller than the emissions from either cokemaking, sintering or ironmaking. Because the electric arc furnace is used primarily for processing scrap metal, the major source of organic material comes from the oil and organic residuals on the scrap and from the carbon electrodes. Obviously, one of the methods that might be used in reducing organic emissions from electric arc furnaces is the segregation of scrap metal according to its oil or organic content and the charging of only scrap with low organic content to the electric arc furnace. Scrap containing high levels of organic materials may be more suitably used in the basic oxygen process where more efficient deconstruction of organics apparently occurs.

5.0 THE IRON FOUNDRY INDUSTRY

The Foundry Industry is basic to an industrial society because sandcasting, although the most primitive method of fabricating metal objects, remains the most economic and most practical method for producing various items. Since the 19th century, it has been an important producer of farm implements, water pipe, and valves. In this century, all energy producing machines, electric motors, internal combustion engines, and turbines, both steam and jet engines, are made from cast metal.

5.1 OVERVIEW

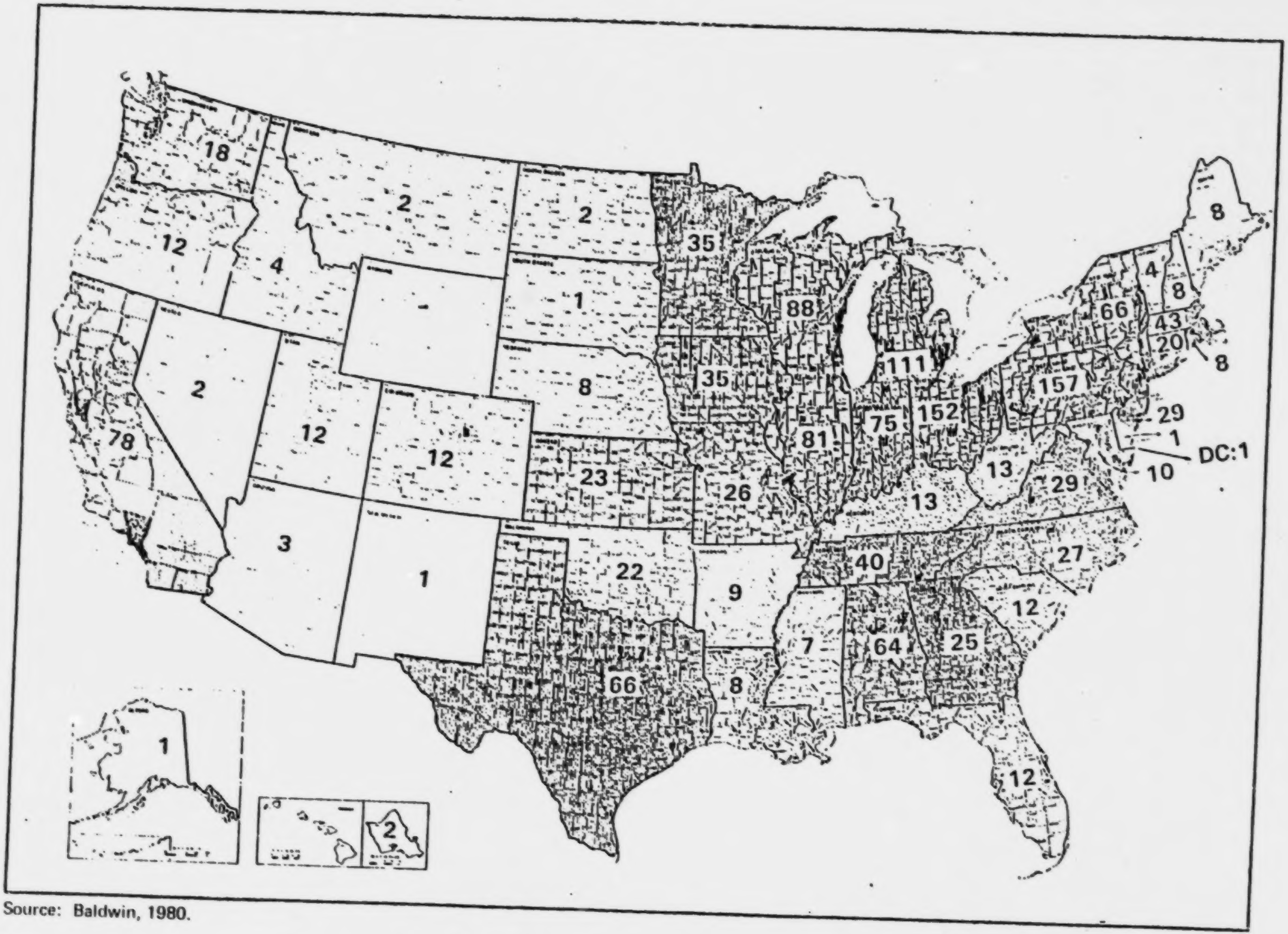
Based on 1976 data, the most recent complete foundry listing available, there were 4,517 foundries in the United States of which 1,367 were iron foundries (Table 5-1). Over the past decade, the industry has shown a trend towards fewer but larger foundries with an average annual attrition rate of approximately 75 plants, most of which are small closely held (privately owned) operations. Today, the industry is in a state of transition from one that has been labor intensive to one that is capital intensive. As a result, the foundry industry now ranks sixth among all manufacturing industries based on value added by manufacturer.

A density distribution of U.S. iron foundries (based on data from Table 5-1) is given in Figure 5-1. The highest concentration of foundries is in Pennsylvania, Ohio, Michigan, Illinois, Wisconsin, New York and Indiana, accounting for more than half of the iron casting capacity of the nation. Two-thirds of the iron foundries are located in metropolitan areas. The decline in foundries has taken place mostly in the smaller metropolitan areas with only a slight change in the larger areas. Figure 5-2 gives the status of casting production in the United States from 1965 to 1982. As shown on Figure 5-2, there has been an overall decline, some of which has been caused by production changes as the steel industry perfects methods of sheet metal fabrication, the reduction in automobile size and the increased usage of other metals (e.g. aluminum) and materials (e.g. reinforced composites etc.).

TABLE 5-1. FOUNDRIES AND IRON FOUNDRIES IN EACH STATE AS OF 1976

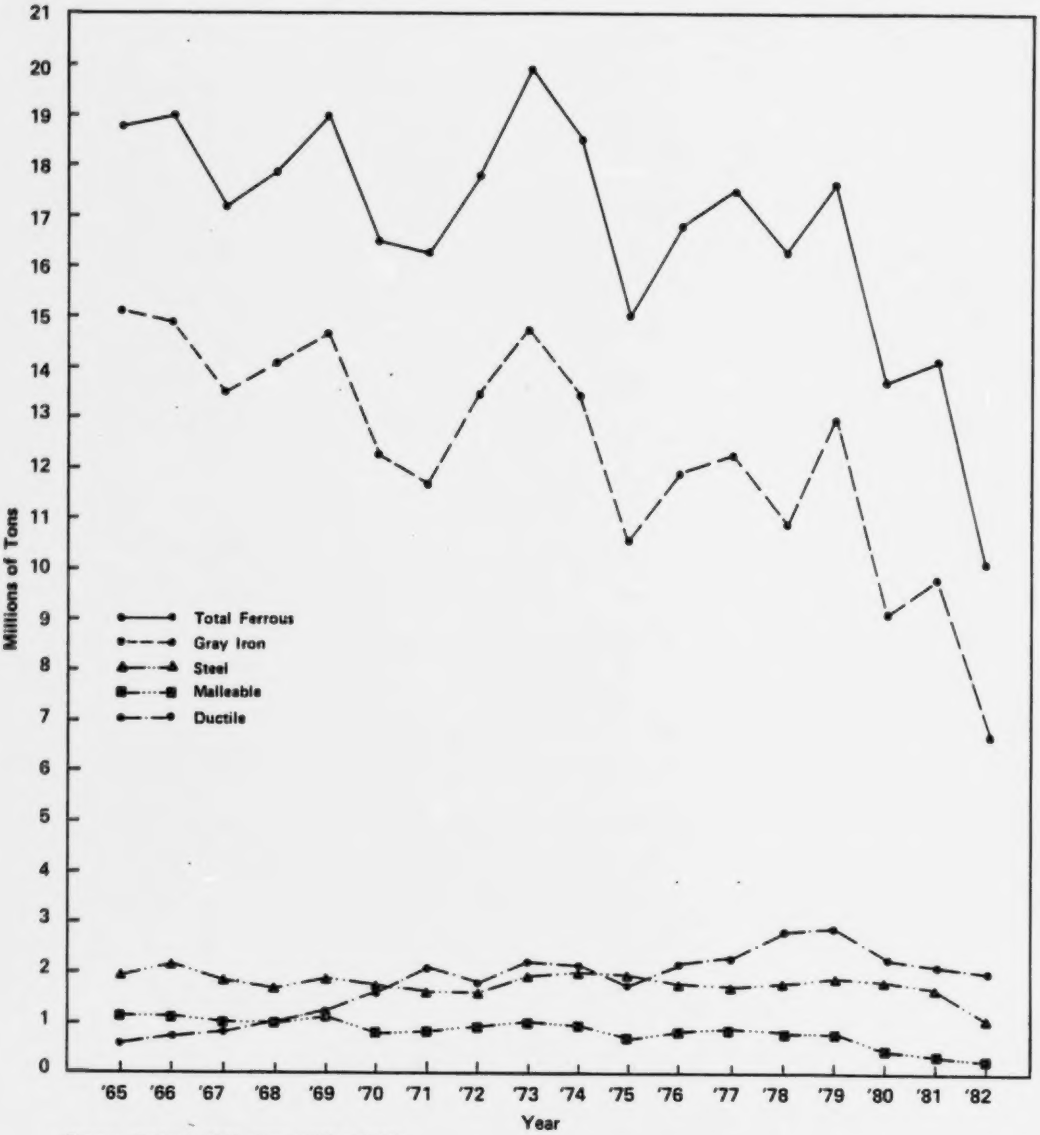
State	Foundries	Iron foundries	State	Foundries	Iron Foundries
Alabama	90	64	Missouri	108	26
Alaska	1	1	Montana	3	3
Arizona	19	3	Nebraska	24	8
Arkansas	43	9	Nevada	4	2
California	440	8	New Hampshire	29	8
Colorado	50	12	New Jersey	134	29
Connecticut	101	20	New Mexico	8	1
Delaware	2	1	New York	282	66
D. C.	2	1	North Carolina	57	27
Florida	60	12	North Dakota	3	2
Georgia	44	25	Ohio	465	152
Hawaii	3	2	Oklahoma	45	22
Idaho	6	4	Oregon	54	12
Illinois	333	81	Pennsylvania	386	157
Indiana	198	75	Rhode Island	57	8
Iowa	77	35	South Carolina	29	12
Kansas	57	23	South Dakota	1	1
Kentucky	30	13	Tennessee	76	40
Louisiana	24	8	Texas	175	66
Maine	16	8	Utah	19	12
Maryland	26	10	Vermont	4	4
Massachusetts	141	43	Virginia	48	29
Michigan	351	111	Washington	53	18
Minnesota	84	35	West Virginia	28	13
Mississippi	16	7	Wisconsin	200	88
			Total	4,517	1,367

Source: Baldwin, 1980.


18
12
2
4
2
1
2
78
12
8
12
3
1
35
35
88
111
75
152
157
66
4
8
8
43
20
8
29
1
DC:1
10
81
26
23
22
13
13
29
27
40
9
7
64
25
12
66
8
12
1
2

Source: Baldwin, 1980.

Figure 5-1. 1978 density distribution of iron foundries.



Source: Baldwin, 1980–Years 1965 to 1977
Modern Casting, American Foundrymen's Society, 1979-1983–Years 1978 to 1982

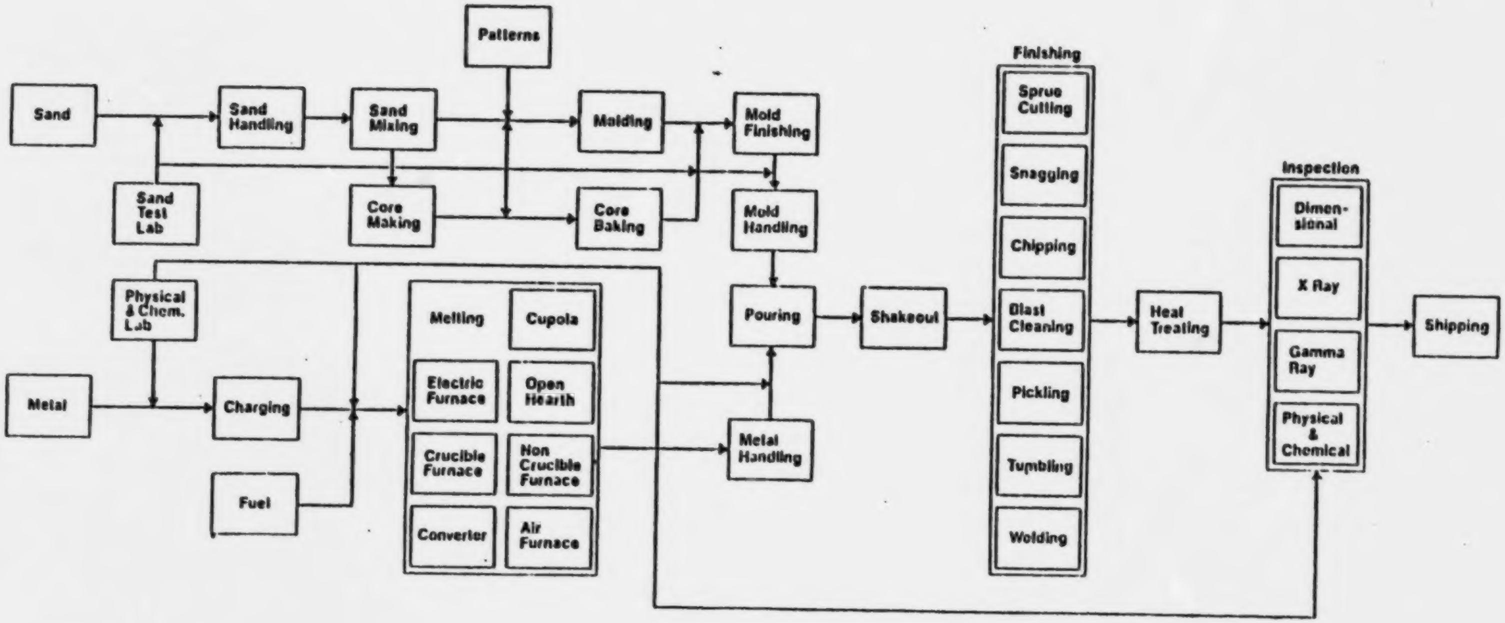
Figure 5-2. Casting production in the United States.

The major change in the foundry industry during the 60's and early 70's has been a decline in the use of the cupola furnace for iron melting and an increase in the use of electric arc furnaces and electric induction furnaces. During the 70's, however, the trend slowed due to the increasing costs of energy and the cupola's more efficient use of energy.

Also, there has been a continuing trend toward automated casting lines and increased use of chemically bonded sand for casting molds. This increased use of chemically bonded sand mold has occurred because it is easy to handle in automated equipment, reduces production cost, requires less highly skilled labor, and produces a better cast product.

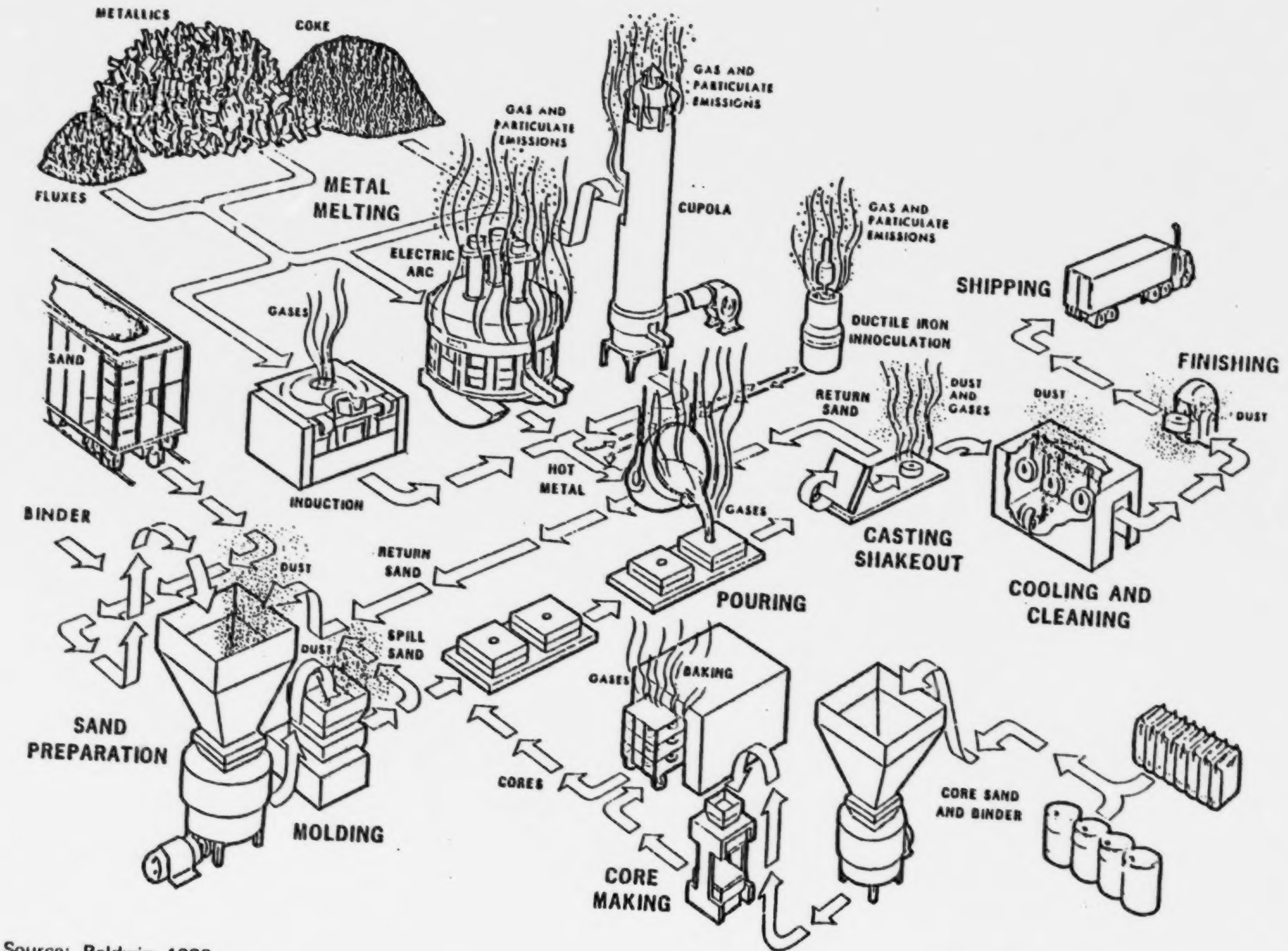
In the modern foundry not only are large quantities of organic polymers used as binders for the chemically bonded sand molds, but also substantial quantities of other organic additives are incorporated into these sand molds for casting purposes. Over 220 million pounds of organic polymers were used by the foundry industry in 1971, and the use is increasing because of the better castings obtained.

Figures 5-3 and 5-4 present a flow sheet and a graphic presentation of the major operations and equipment involved in the foundry industry. Operations within a typical foundry involve mold preparation, metal melting, metal pouring, and casting treatment. Specific operations involved in mold preparation include sand preparation where the sand and binder materials are mixed, mold fabrication, and core making which also includes core bake out. In the melting operation, metallic stock including pig iron and metal scrap, coke, and fluxes are mixed and charged into furnaces where either electrical energy or fuel combustion are used to provide the heat for melting the charge. The melted metal which is discharged into a ladle is then transferred to the pouring area where it is poured into the assembled molds. From the pouring area, the filled molds are transferred to a holding area for cooling and then to the casting shakeout station. After the casting is separated from the mold, it under goes additional cooling and cleaning to remove the sand. The cleaned casting is then subjected to the final finishing operations that may be required for the end product.


Patterns
Sand
Sand Handling
Sand Mixing
Molding
Mold Finishing
Sand Test Lab
Core Making
Core Baking
Mold Handling
Physical & Chem. Lab
Metal
Charging
Fuel
Melting
Cupola
Electric Furnace
Open Hearth
Crucible Furnace
Non Crucible Furnace
Converter
Air Furnace
Pouring
Metal Handling
Shakeout
Finishing
Sprue Cutting
Snagging
Chipping
Blast Cleaning
Pickling
Tumbling
Welding
Heat Treating
Inspection
Dimen-sional
X Ray
Gamma Ray
Physical & Chemical
Shipping

Source: Baldwin, 1982.

Figure 5-3. Typical foundry production flow chart.


METALLICS
COKE
FLUXES
METAL MELTING
GAS AND PARTICULATE EMISSIONS
GAS AND PARTICULATE EMISSIONS
CUPOLA
ELECTRIC ARC
GASES
SAND
INDUCTION
HOT METAL
GAS AND PARTICULATE EMISSIONS
DUCTILE IRON INNOCULATION
SHIPPING
FINISHING
DUST
DUST
RETURN SAND
DUST AND GASES
GASES
CASTING SHAKEOUT
COOLING AND CLEANING
BINDER
DUST
RETURN SAND
SPILL SAND
DUST
POURING
SAND PREPARATION
MOLDING
GASES
BAKING
CORES
CORE MAKING
CORE SAND AND BINDER

Source: Baldwin, 1982.

Figure 5-4. Iron foundry process flowsheet, emission sources.

5.2 ORGANIC MATERIAL INPUTS

On a macroscopic basis organic material inputs for a typical foundry operation may include the following:

- Polymeric binders and organic additives
- Coke
- Fuel
- Raw Material Residuals (e.g., oil and lubricants on scrap metal)
- Water contaminants
- Carbon electrodes
- Finishing materials for castings (e.g., coating oils and paints)

The absolute and relative quantities of the above organic materials and there point of use within a foundry may vary substantially from foundry to foundry. This variation depends on a number of factors including the foundry size, equipment, and process operations; production rate; product type and specifications; operating practices; and production cost considerations. For example, a number of different furnaces such as an electric arc furnace, induction furnace, a cupola, and an open hearth can be used to melt the scrap iron. A particular foundry may use one or more of these furnaces, thereby, dictating whether or not carbon electrodes (used in electric arc furnace) are involved. The type and quantity of polymeric binder and organic additives is influenced by production cost, types of molds used, and product type and specifications. The amount of organic residuals on the raw material is effected by the availability and cost of the raw materials as well as foundry operating practice.

As previously discussed polymeric binders and organic additives for the fabrication of casting molds are a major organic material input to a modern foundry and are being used in steadily increasing quantities. Some of the organic core binders being used are shown in Table 5-2. These binders which represent a wide variety of classes of compounds would provide

TABLE 5-2. ORGANIC CORE BINDERS

- Oils
  - Core oils (oven-baked)
  - Oil-oxygen (no-bake)

- Urethanes
  - Alkyd isocyanate (no-bake)
  - Phenolic isocyanate
    - a. Gassed
    - b. Ungassed (no-bake)

- Hot box (heated core box)
  - Urea-formaldehyde
  - Phenol-formaldehyde
    - a. Novalak
    - b. Resole

  - Furan

  - Modified
    - a. Urea-formaldehyde/furfuryl alcohol (UF/FA)
    - b. Phenol-formaldehyde/furfuryl alcohol (PF/FA)
    - c. Phenol-formaldehyde/urea-formaldehyde (FF/UF)

- Acid no-bakes

  - Furan
  - Phenol-formaldehyde

Source: Baldwin, 1980.

a variety of organic vapors and partial combustion products that are emitted to the atmosphere within a foundry. Baldwin (1980) has reported potential decompostion products of a number of polymeric binders and organic additives used in the foundry industry.

Coke which may be either coal-based or petroleum-based is used in the foundry as fuel and as a reactant for metal refining. It represents another major organic material input in foundry operations. This coke may be a source of a variety of organic compounds due to volatile matter present from incomplete coking (green coke) and due to organic oils and vapors absorbed during coke storage and handling.

The raw material residuals are generally lubricating oils, greases, cutting and annealing oils, coating oils, and other organic protective coatings associated with scrap metal. These organic residuals enter the foundry in the melting operation where they are vaporized, cracked, and partially burned in the furnaces. Foundry operating practices in segregating clean and dirty scrap, the type of melting furnace, and the source of scrap are the dominating factors affecting the amount of organic emissions in the foundry from these residual organics.

The carbon electrodes used in an electric arc furnaces are another source of organic materials introduced into the foundry, albeit, they probably represent a minor source. Although these electrodes are primarily graphitic carbon, they typically contain a significant amount of organic binder for their mechanical strength and structural integrity. In the electric arc furnace, organic species are generated through the vaporization and cracking of these pitch binders and through chemical reactions involving these binders and the graphitic carbon in the plasma zone surrounding the electrodes.

The finishing or final production step on the foundry castings may involve among other operations surface cutting and machining, oil bath annealing, and protective coating application. These steps typically involve the use of organic materials and represent another source of organic emissions within a foundry. The amount of these organic emissions, however, is highly dependent on foundry production schedules and product specifications; and therefore, is not only highly variable within a foundry, but may be highly variable between foundries.

Lubricants are another organic material input source which contributes to organic vapor emissions in a foundry. These lubricants, however, probably represent a minor source of organic emissions in a foundry as compared to the iron and steel industry because foundry machinery using the bulk of the lubricants is operated at substantially lower temperatures than the machinery, i.e. rolling mills, in the iron and steel industry.

5.3 ORGANIC EMISSION SOURCES AND CONTROL

Sources of organic vapor emissions in iron foundries are summarized in Table 5-3. As shown in Table 5-3, major organic emission sources are associated with furnace operation in metal melting, metal pouring and filled mold cooling, casting shakeout, casting treatment and finishing, and mold fabrication. Previous Research Triangle Institute studies under EPA Contract Nos. 68-02-2630, Task 2, and 68-02-3152 having investigated iron foundry atmospheric emissions from cupola and electric arc furnaces, pouring and cooling operations, casting shakeout, and metal inoculation. Discussions of organic emission sources within the foundry industry and prevailing atmospheric pollution control practices are presented in this section.

5.3.1 Mold Fabrication

A number of different types of molds are used in the foundry industry. Some of the major mold types include: green sand, inorganic bonded sand, organic bonded sand, permanent molds, and physically bound molds. The green sand mold, which is the original mold type used in the foundry industry, is still the predominant type used today. The term "green sand" prefers to the type mold where the chief bonding agent is clay, usually a western or southern bentonite. The clay is plasticized with about 3 to 5 percent water and organic materials such as sea coal, wood flower, oat

TABLE 5-3. CHARACTERISTICS AND SOURCES OF EMISSIONS IN VARIOUS FOUNDRY DEPARTMENTS

Department	Operation	Type	Emissions[a] concentration	Particle[a] size (microns)	Relative[a] controllability	Relative cost
Molding, pouring, and shakeout	Molding	Sand	Light	Coarse	Easy	Low
		Dust				
		Vapor				
	Pouring					
	Gray and ductile iron	Core oil vapors	Heavy		Moderate	Medium
	Malleable iron	Facing fumes	Heavy			
		Metal oxides	Light	Fine to medium		
		Fluoride fumes	Heavy			
		Magnesium oxide fumes	Heavy	0.01 to 0.4		
		Synthetic binder smoke and fumes	Moderate to heavy			
	Shakeout	Sand fines	3 to 5 g/ft^3	50%-2 to 15	Moderate	Medium
		Smoke	Heavy	0.01 to 0.4		
		Steam	Heavy			
		Dust	3 to 5 g/ft^3	50%-2 to 15		
Cleaning and finishing	Abrasive cleaning	Dust	3 g/ft^3 and up	50%-2 to 15	Easy	Low
	Grinding	Metal dust	5 g/ft^3 and up	Above 7	Medium	Low
		Sand fines	3 to 5 g/ft^3	Fine to medium		
		Abrasives	0.5 to 2 g/ft^3	50%-2 to 7		
		Wheel bond material	Light	Fine		
		Vitrified resins	Light	50%-2 to 15		

(continued)

TABLE 5-3 (continued)

Department	Operation	Type	Emissions[a] concentration	Particle[a] size (microns)	Relative[a] control-lability	Relative cost
	Annealing and heat treating	Oil vapors		0.03 to 1	Moderate	Low
	Painting spray and dip	Volatile fumes			Easy	Low
		Paint spray carryover	0.5 to 2 g/ft^3	50%-2 to 7		
Sand conditioning	New sand storage	Water spray carryover				
		Fines	3 to 5 g/ft^3	50%-2 to 15	Moderate	High
	Sand handling system	Fines	3 to 5 g/ft^3	50%-2 to 15	Moderate	Medium
	Screening	Steam				
		Fines	3 to 5 g/ft^3	50%-2 to 15	Easy	Low
	Mixing	Fines	3 to 5 g/ft^3	50%-2 to 15	Easy	Medium
		Flour	Moderate	Fine to medium		
		Bentonites	Moderate	Fine to medium		
		Sea coal	Moderate	Fine to medium		
		Cellulose	Moderate	Fine to medium		
	Drying and reclamation	Dust	1/2 to 2 g/ft^3	50%-7 to 15	Easy	Medium
		Oil vapors				
Coremaking	Sand storage	Sand fines	Heavy	Fine	Moderate	High
		Flour	3 to 5 g/ft^3	50%-7 to 15		
	Coremaking	Binders				
		Sand fines	Heavy	Fine to medium	Moderate	Medium
		Dust	Light	Fine to medium		
	Baking	Vapors			Easy	Medium
		Smoke				

Source: Baldwin, 1980.

[a] Represents the view of Bates and Scott (1976).

hulls, and substances that are typically waste residues of organic chemical production. These substances are added to the clay sand mixture in amounts up to 8 percent. The purpose of the organic addition is to cushion the thermal expansion, to provide a reducing atmosphere, and to promote graphite formation at the sand-metal interface which gives a better finish to the metal.

Inorganically bonded molds which use plaster of paris, sand, and a form of portland cement as the major ingredients are used almost exclusely for small high quality castings in speciality work because the manufacturing time involved makes them very expensive. The most promising type of inorganic binder used in these molds is sodium silicate. These inorganically bonded molds, made in the same way as the green sand molds are virtually nonpolluting; but are very strong and often pose problems in removal of the mold from the metal.

Organically bonded sand molds, using a broad range of synthetic resin organic binders, are fabricated by a variety of mold making techniques. These techniques include shell molding, hot box molds, cold set binders, no bake resins, oils, and full mold process. Some of the more popular organic binders used are listed in Table 5-3. Nearly all shell molds use the phenol-formaldehyde binders which require baking for about one minute. This baking operation is one source of organic vapor emissions associated with mold fabrication.

Hot box molds, like shell molds which use thermosetting resin binders such as urea-formaldehyde, furan, and phenol-formaldehyde/furfuryl alcohol resins in addition to the phenol-formaldehyde resin used in shell molds also require baking to set the resin. In recent years, however, hot box molds have become unpopular because of the time and energy consumption required and have been replaced by cold set binder molds.

Cold set binders, developed about 1967, use urethane resins which are hardened by passing a catalyst gas [triethylamine (TEA) or dimethylethylamine (DMEA)] through the mold. The mold itself is actually made of two resins, a phenolic resin, and a polyisocyanate mixture which is incorporated with the sand. After the mold has been formed, catalyst gases are blown through the mold which harden the resins in about 3 to 15 seconds, depending on mold size. This catalyst gas is another source of organic emissions from the mold fabrication process.

In the fabrication of no-bake resin molds, a resin and a catalyst hardener are mixed with the sand, and the mixture is placed into a pattern to form the mold. The hardener cures the resin over a relatively short period of time. The earliest no-bakes used drying oils as binders; whereas, today they generally use special urethane in phenol-formaldehyde resins.

The oil bound molds represent the earliest form of chemically bonded molds. The core oils used were various oil mixtures that hardened when baked. The drying oils, such as linseed and tung oil, that are used in no-bake operations are oils that hardened by reacting with the oxygen in the atmosphere.

In the full mold fabrication process, a styrofoam pattern is placed in a flask and either organically bonded or physically bonded sand is packed around it. The completed flask is sent to the pouring station where the molten metal is poured directly on top of the styrofoam. As the molten metal enters the mold the styrofoam either vaporizes or burns to graphite which promotes a fine finish on the metal surface.

Physically bonded molds represent the newest casting method and holds the greatest promise for low environmental effects. These physically bonded molds, also termed "third generation molds," include sand molds in which the sand is held in position by air pressure and powder iron molds in which powder iron used in place of sand is frozen into position by a magnetic field. Both of these processes are similar to the full mold process in that a styrofoam pattern is made, placed in a flask, and surrounded by sand or grandular iron. Unlike the full mold process, however, these third generation molds do not use chemical binders.

In the magnetic process, the flask is placed in a magnetic field, which bonds the iron particles together. The hot metal is then poured on top of the styrofoam. After the metal has cooled, the magnetic field is turned off and the cast object is removed. In the sand process, after the sand is placed around the styrofoam pattern in the flask, it is stabilized by applying a vacuum through vents on the bottom of the flask which pulls the sand down and packs it tightly. Another variation of this latter process utilizes a layer of plastic over the top of the mold thereby giving maximum pressure from the atmosphere against the sand.

Since these third generation molds do not use chemical binders, they are relatively free of organic vapor emissions. Although a small amount of polymer material is vaporized, the nature and quantity is such that the pollutants expected from them is minor compared with the chemically bonded molds.

In summary, the chemically bonded molds represent the major source of organic vapor emissions in the mold fabrication process. Of the chemically bonded molds, the ones requiring bake out or catalyst gases to cure the binder account for the greatest level of organic vapor emissions during mold fabrication.

5.3.2 Cupola Furnace Iron Melting

The cupolas furnace which has long been considered one of the most economical devices for melting iron is one of the furnace types used in foundries for melting iron. Although many foundries in recent years have converted to induction furnaces for environmental reasons, increased electricity costs and improved cupola design and operating methods plus the availability of suitable air pollution control devices have fostered continued widespread use of the cupola in foundry melting operations.

Cupola melting is also preferred in some cases for metallurgical reasons. Properties of cast metals are dependent on the chemical composition and the time temperature history. For example, trace quantities of components will effect properties such as surface tension, and nucleation rate in manners that are not yet completely understood. Iron melted in a cupola has natural characteristics favored by foundrymen such as a low tendancy to chill (an undesireable freezing structure) and good fluidity, machinability, and shrinkage characteristics. Iron melted in induction and electric arc furnaces does not have the same characteristics. For this reason, even though foundries have moved towards increased use of induction and electric arc furnaces in recent years, the cupola furnace is still used for about 70 percent of the cast iron production in foundries.

The cupola which appears very much like a scaled down version of a blast furnace is a vertical tube furnace consisting of a steel shell lined with refractory bricks. The bottom is a removable steel door which is covered with sand to protect it from the molten iron. Less than one furnace diameter above the bottom, a set of tuyeres through which air or oxygen is blown into the charge circle the furnace.

Coke, iron, and limestone or other fluxing agents are dropped into the top of the furnace. The coke may amount from 8 to 16 percent of the iron, depending on the type of furnace and method of operation. The charge is usually made in the form of alternating layers of iron and coke, which mix together as the charge descends into the furnace.

This charge may be introduced vertically from the top, or more commonly through a door in the side of the furnace near the top. The air blasts from the tuyeres provide oxygen to burn the coke. The high efficiency of the cupola results from the efficient heat transfer from the hot gases to the iron as the gases rise through the charge.

Good cupola operation requires scheduling mold pourings to consume the full output of the cupola. This scheduling allows the cupola to be operated at a uniform rate which gives uniform iron chemistry. Some smaller foundries, will turn the air blasts off and on to obtain iron at a rate less than the cupola's optimum. This cyclic operation not only adversly affects iron chemistry, but also affects the temperature of the afterburner that sometimes results in failure of the afterburner to remove oily smoke from charging dirty scrap.

Advances in cupola design and operating methods have helped to reverse the trend towards the use of induction and electric arc furnaces in foundries as a means to reduce atmospheric emissions. The four advanced cupola designs are: 1) the hot blast cupola, 2) the divided blast cupola, 3) the gas cupola, and 4) the oxygen enriched blast cupola. Basically these four designs represent schemes to reduce or eliminate coke usage by increasing the cupola's thermal efficiency. Although these designs offer promise in reducing the cupola's emission, they are not in widespread use.

5.3.3 Electric Arc Furnace Iron Melting

Electric arc furnace (EAF) is a relatively low cost, flexible device that can be used for either melting iron or refining steel. In 1978, 1,074 EAF's were in use in 440 foundries. In foundry practice, the size of these furnaces range from 0.03 tons (60 lbs.) to 30 tons. Most EAF's in use have capacities of 1 ton or more with 10 tons being about the average capacity and with a few having capacities exceeding 15 tons.

The EAF itself is a squat cylindrical steel shell lined with either acidic or basic refractory. Its lid or roof which is also refractory-lined contains three holes for the insertion of graphite electrodes, powered by three phase alternating current. This roof can be lifted and swung aside for charging the EAF.

Materials charged to EAFs include: iron and steel scrap, iron ore, coke, alloying metals, and fluxing material such as limestone, silica, and fluorspar. Usually the fluxing materials and low density scrap are charged first to protect the refractory lining by cushioning the fall of the more dense scrap material. Organic contaminants in the metal scrap, the coke, and electrodes are the primary source of organic emissions from an electric arc furnace.

The production of iron (or steel in the case of a steel foundry) in an EAF is a batch operation consisting of several sequential actions. The production cycle usually takes 1½ to 5 hours depending on the furnace, operating techniques, and type of metal alloy being made. In the initial phase of the cycle as the electrodes melt the scrap, a pool of metal forms which melts more scrap by thermal conduction. Radiant heat from the electric arc also melts the metal surrounding the arc.

During this initial phase in which the scrap metal temperature is gradually increased, the organic contaminants in the scrap and some of the organic binder in the graphite electrodes may volatilize and enter the atmosphere through the holes in the furnace roof or through the air pollution control system which is designed primarily for particulate control. The graphite electrode in the electric arc furnace are consumed at a rate of approximately 10 lbs. per ton of metal produced. This electrode consumption rate, however, may be higher if the air pollution control system is poorly designed and draws an unnecessary amount of air past the hot portions of the electrodes, thereby, increasing their rate of combustion. Although the electrodes generally burn to carbon monoxide, which is subsequently oxidized further to carbon dioxide when fresh air is added to the air drawn from the furnace, some organic species may be generated by the chemical reactions that occur in the plasma region of the electric arcs.

5.3.4 Induction Furnace Iron Melting

The induction furnace, which is a well proven device for melting most metals under a wide variety of conditions, ranges in sizes as small as one ounce capacity for laboratory work up to the world's largest of 121 tons. In foundry use, normal range of furnace sizes is from 0.025 to 70 tons, but usually not over 15 tons for melting purposes. The majority of induction furnaces for melting are under 1 ton in capacity, with the electric arc furnace taking over usually at the 1 ton level. The most common foundry use of larger induction furnaces is not for melting, but as holding furnaces to receive hot metal from cupolas and to maintain it at a desired temperature. These induction furnaces may be made to operate in ultra high vacuum chambers or under the demanding environment of a production shop.

There are two basic types of induction furnaces. The channel furnace has a refractory line channel in the bottom where liquid metal can form a complete electrical circuit around a transformer core. This design induces a current in the metal, which heats it, and the interaction of the magnetic fields causes the liquid metal to circulate into the main vessel where it heats the charge. In the much simpler crucible or coreless induction furnace design, a cylindrical crucible is wound with water cooled electrical conductors which places the metallic charge within a solenoid coil. The magnetic field and current induced in the charge melts and stirs it.

The induction furnace is considered the cleanest operating device available for melting metal. The organic emissions that do occur, are the results of the boiling off of organic contaminants on the scrap. Since totally clean scrap is seldom obtained, a canopy hood and exhaust system to control emissions from the furnace is typically used. When nontoxic alloys are melted general ventilation is usually employed to control emissions within the foundry building.

5.3.5 Metal Pouring and Filled Mold Cooling

Iron castings are made by pouring liquid metals into molds, then the filled molds are placed in a cooling area until the castings solidify. In the pouring operation, iron is tapped from the cupola, electric arc furnace, or induction furnace into a small ladle of 1/3 to 1 ton capacity. The ladle, which is suspended from an overhead conveyor, is moved along the conveyor line of moving molds by the operator. When the operator has positioned the ladle with respect to the mold, he tilts the ladle and pours the metal into the sprue hole.

Emissions from pouring can be typically captured by two methods. The most convenient method for a large foundry is the hooded pouring station where air is blown down from the front edge of the hood and drawn up by the lower grill. A push-pull system utilizing an incoming draft from a floor grating that is drawn out by a hood is also very effective. In smaller foundries, portable exhaust hoods attached to the ladle support system along the overhead conveyor are used.

In the foundry, the pouring and cooling operation is a significant source of organic vapor emissions. During the pouring operation, the mold and core are usually enclosed in a flask from which emissions evolve within seconds of pouring. From laboratory tests (Bates and Scott, 1976) in which a 30 pound, 4-inch cube was cast in an uncored green-sand mold containing 5 percent sea coal, carbon monoxide concentrations peaked at about 1900 ppm after five minutes and the total hydrocarbons reached a maximum of 1215 ppm after six minutes. The sand-to-metal ratio used was 3 to 1. Also in the same study, green sand molds with various formulations of course sand were tested. Maximum emission values for carbon monoxide were reached after one to five minutes, for carbon dioxide after one minute, for methane after one to five minutes, and for total hydrocarbons after one to six minutes.

The experiments of Bates and Scott that most closely approximate the pouring conditions were the sealed flask experiments. The effluent they collected from flasks after pouring was analyzed by GC-MS and several carcinogenic compounds were identified. No quantification was given for these compounds, however.

An EPA study of organic vapor emissions from foundry casting processes, performed by Research Triangle Institute (Baldwin, 1980), examined the nature and characteristics of the vapor emissions during the pouring and cooling operations. According to the operative mechanisms discussed, the maximum emission of higher molecular weight organic substances occurs during pouring and initial cooling, while the release of the higher molecular weight organics during casting shakeout is a function of metal temperature.

There are, however, competing mechanisms during pouring and initial cooling which affect the amount and nature of organic vapors released. Although major organic vapor emissions on pouring come from the top surface of the sand around the sprue hole, the majority of the gases are formed at the sand metal interface inside the mold. These organic vapors which have to pass through the sand to escape are largely trapped within the sand of the mold. These trapped organics tend to be chromatographically separated with the higher molecular weight substances closer to the higher temperature metal-sand interface, and the lower molecular weight organics further away from this interface in the cooler regions of the sand. Also, large quantities of H_2, CO, and CH_4 are produced and ignite at the time of pouring. These burning gases may be seen for several minutes after pouring. Some of the organic vapors particularly the lower molecular weight ones are burned during this ignition.

The foundry studies of organic emissions from casting operations (Baldwin, 1980) did not substantiate the laboratory data from the Bates and Scott (1976) study. The reported differences between the two studies in the quantity and type (class) of organic emissions from iron casting has been attributed (Baldwin, 1980) to differences in the vapor collection method/apparatus, mold design, and extent of vapor combustion at mold vents. For this study, the organics emissions data from the foundry tests (Baldwin, 1980) were used to determine organic emission factors.

After pouring, on an automatic casting line, the molds are conveyed to a cooling room where they are held until casting shakeout. In this room, the conveyor system is designed to provide maximum track length, i.e., time delay. Cooling time varies from 45 minutes to 2 hours on the automated lines and may extend to over night in small nonautomated foundries. In some places, the cooling occurs in a tunnel rather than in a room. Although the minimum required cooling time will vary with the size of the casting, the actual cooling time, which depends on production rate may be quite variable. As shown in the RTI study (Baldwin, 1980), the cooling time is a major factor in shakeout emissions. An increase in cooling time reduces organic vapor emissions during shakeout because the sand containing adsorbed organics comes in contact with the metal at a lower temperature, thereby, causing less devolatilization of these adsorbed organics.

5.3.6 Casting Shakeout

Casting shakeout operations involve the removal of the castings from the sand molds. The most elementary method of removing the castings from the mold is to dump the mold and hook or pull out the casting from the sand. When a production rate is required, however, the molds are automatically inverted and dumped onto a vibrating grate which shakes out the sand and separates the casting. The sand falls through the grate and onto a conveyor belt which carries it to the conditioning and reprocessing system. In some cases, the shakeout could be a long vibrating grate (30 meters) such as that used for engine blocks and heads where much internal core sand must be removed. There are variations of this vibrating grate shakeout system such as heavy screen drums that rotate batches of castings and long cylindrical perforated cylinders that tumble the parts.

The shakeout has the potential to generate the most organic emissions of the many foundry operations. By the time the mold assembly reaches the shakeout, the bulk of the thermal decomposition of the mold/core materials has occurred. The products of thermal decomposition tend to be lower molecular weight materials which vaporize and defuse away from the hot metal-sand interface into the cooler sand where some of the organic vapors condense and adsorb on the cooler sand in the mold. Most organic compounds with boiling points below 100°C are lost during mold cooling.

During shakeout, flash vaporization and emission of these condensed pyrolysis products occurs when the cooler sand comes into contact with the hot sand surrounding the metal and the metal itself. Although further decomposition of the organic species may occur during shakeout, it is less than the decomposition that occurs during pouring. The experiments of Bates and Scott (1976) showed higher peak hydrocarbon emissions (1500 ppm) during shakeout than during pouring and cooling, although the average concentrations were lower during shakeout. Toeniskoetter and Schafer (1977) sampled many foundries for selected emissions from different binder systems. Their results show that the isocynate concentration is frequently greater at shakeout than at the pouring station. Organic vapor emissions from green sand shakeout, measured in an RTI study (Baldwin, 1980) are summarized in Table 5-4.

TABLE 5-4. SUMMARY OF ORGANIC VAPOR ANALYSIS FROM GREEN SAND SHAKEOUT[a]

Category	Found (mg/m³)
Aliphatics	0.72
Haloaliphatics	0.22
Substituted benzenes	2.45
Halobenzenes	0.24
Fused aromatics	2.45
Hetero N compounds	0.56
Hetero O compounds	0.10
Hetero S compounds	0.10
Alkyl S compounds	0.06
Nitriles	0.01
Aldehydes, ketones	0.10
Nitroaromatics	0.01
Ethers, epoxides	0.10
Alcohols	0.56
Phenols	0.56
Amines	0.56
Amides	0.47
Esters	0.15
Carboxylic acids	0.46
Sulfonic acids	0.05
GRAV concentration	9.85
TCO concentration	163.8

Source: Baldwin, 1980.

[a] Sample No. 1; Emission rate = 1.22 lb/ton metal cast.

5.3.7 Cleaning and Finishing

The last foundry production steps in casting manufacture are the cleaning and finishing operations. After the castings are removed from the molds, the sprue gates and risers must be broken off. Also, the "flash" or sharp edge which occurs in cases where separate parts of the mold did not mate perfectly must also be removed. This final finishing is accomplished by grinding off these imperfections. In addition, other finishing operations such as surface machining, welding, pickling, heat treatment, and painting or coating may be required to meet casting specifications.

Although, atmospheric emissions in the cleaning and finishing operations are predominantly particulates, several finishing operations such as heat treatment where the castings are immersed in annealing oil and protective coating application where paint or coating oils are applied to control corrosion may generate organic vapor emissions. The extent to which these latter treatments are used is highly dependent on product specifications for the casting and is, therefore, quite variable in foundry operations. No information on organic emissions from foundry finishing operations was found in the literature. Moreover, since organic emissions from this source are probably minor compared to other sources within the foundry and their highly variable nature defies emissions estimation, no further attempts were made in this study to determine organic emission factors for foundry finishing operations.

5.4 EMISSION FACTORS AND POLLUTION CONTROL

Organic emission factors for point sources within the foundry industry are presented in Table 5-5. Also included in this table are estimates of total organic emissions by source for the foundry industry based on 1981 production data. The emission factors which were obtained from two RTI studies (Baldwin, 1980, 1982) sponsored by EPA (Contract Nos. 68-02-2630 and 68-02-3152), represent the currently available data suitable for determination of emission factors for the foundry industry. Based on the

TABLE 5-5. ORGANIC EMISSIONS FROM POINT SOURCES WITHIN IRON FOUNDRIES

Emission source	Organic emission factor (lb/ton)	Organic emission factor (kg/MT)[a]	EF Rating	U.S. annual production (1981) (tons)	Organic emissions (tons)	References
Mold fabrication	D.N.A.[b]	-	-	-	-	-
Cupola furnace	0.181	0.0904	C	13,340,000[c]	1,207.5	Baldwin, 1982
Electric arc furnace	0.347	0.174	C	5,720,000[c]	992.2	Baldwin, 1982
Induction furnace	D.N.A.	-	-	-	-	-
Inoculation	0.0052	0.0026	C	3,380,000[d]	8.8	Baldwin, 1982
Pouring and cooling	0.136	0.0681	C	19,060,000[e]	1,296.2	Baldwin, 1982
Casting shakeout						
Uncontrolled	1.228	0.614	C	19,060,000	11,703.8	Baldwin, 1980
After wet scrubber	1.024	0.512	C	-	-	-
Finishing operations	D.N.A.	-	-	12,390,000[f]	-	-
Totals	2.45[g]	1.23		12,390,000	15,208.5	

[a] Emission factors expressed per ton or metric ton (MT) of metal melted.

[b] Data not available.

[c] Assumes 70 percent metal melted in cupola furnace (Baldwin, 1982) and 30 percent in electric arc furnaces.

[d] Based on net castings production of ductible metal (2,200,000 tons) and ratio of net castings to molten metal inoculated of 0.65.

[e] Based on ratio net castings to metal melted of 0.65 (Calspan Corp., 1977) and assumption all metal melted is poured.

[f] Net gray iron, ductible, and malleable castings produced in 1981 (Figure 5-2).

[g] Overall organic emission factor for iron foundries based on net tons or metric tons of castings (gray iron, ductible, and malleable) produced.

credibility rating criteria set forth earlier, the emission factors presented here are rated C. This C rating of the organic emission factors from the RTI study was applied because the Level 1 analysis, which was used in the RTI study, does not use duct traverses or determine isokinetics in emissions sampling. In addition, a significant number of foundries were not sampled for a statistically valid estimate of industry-wide organic emission factors.

In Table 5-5, mold fabrication, induction furnaces, and finishing operations were identified as potential point sources of organic emissions in the foundry industry, however, data were neither available nor adequate to allow determination or estimation of emission factors for these three sources.

Jonsson and Thyberg (1976) measured concentrations from toxic organics in the atmosphere near mold fabricating operations in which cold-setting furan, Ashland cold-box, hot-box, and shell methods were used. Although they reported measuring phenol, formaldehyde, isocyanate, furfuryl alcohol, and triethylamine concentrations in the atmosphere of 3, 2, 0.005, 10, and 7 ppm, respectively, they did not measure total organic emissions and their data were not suitable to estimate emission factors even for the organic compounds identified.

The induction furnaces which are used primarily to hold molten metal produced in cupola electric arc furnaces do not represent a major organic emission source relative to the number of induction furnaces in use because of the limited number used for melting scrap. Those induction furnaces used for melting scrap, however, may produce significant levels of organic emissions if extremely dirty scrap is used. Since virtually no oxygen is present in the atmosphere within an induction furnace, the organic contaminants in the scrap vaporize during heat-up and escape from the top of the furnace without being burned. These organics are either vented directly to the atmosphere within the foundry or captured by hoods and vented to the atmosphere outside the building.

As discussed previously, finishing operations in which organic material such as paints and oils are used are highly variable and probably represent a minor source of organic emissions in the foundry industry. The expected major organic emission sources in finishing operations would occur in applying paint or protective oil coatings on the castings and in oil annealing of castings, typical of malleable iron production.

From Table 5-5, casting shakeout from chemically bound molds appears to be the foundries' major organic emission source, accounting for approximately 77 percent of the organic emissions; followed by pouring and cooling operations accounting for 8.5 percent of the organic emissions; cupola furnaces for 8 percent; electric arc furnaces for 6.5 percent; and inoculation with a negligible overall organic emission contribution. The magnitude of the casting shakeout emissions which is based on the assumption of industry-wide exclusive use of green sand molds is probably high because other methods use different levels of organic materials. However, in terms of total foundry industry organic emissions, this over-estimation of casting shakeout emissions partially compensates for organic emissions from mold fabrication, induction furnaces, and finishing operations which are not included in a total estimate.

To develop an overall organic emission factor and to estimate the magnitude of organic emissions that might be representative of a typical foundry operation, typical (hypothetical) foundries for the production of gray and ductile iron and for the production of malleable iron were established. The average size of the gray and ductile foundry was taken to be 11,000 net tons castings/year and the average size malleable iron foundry was taken to be 14,000 net tons castings/year (Calspan Corp., 1977). Since there are differences in design, equipment, and operating practices between foundries, it was assumed that these typical or hypothetical foundries reflected industry-wide operations in terms of equipment, production configuration, and relative production rates for the various processing operations. The basic assumptions used for the two typical foundries are given below in Table 5-6. The organic emissions and emission factors per ton of melted metal and per net ton of castings for the two typical foundry cases are presented in Table 5-7.

TABLE 5-6. ASSUMPTIONS FOR A TYPICAL IRON FOUNDRY

Basis	Gray and ductile iron foundry	Malleable iron foundry
1. Production capacity (net ton castings/yr)	11,000	14,000
2. Ton net castings/ton melted metal ratio	0.65	0.65
3. Melting furnace production (% metal melted)		
Cupola furnace	70%	70%
Electric arc furnace	30%	30%
4. Ductile iron production (% of total)	16%	N.A.[a]
5. Metal poured (% of metal melted)	100%	100%

[a] Not applicable.

TABLE 5-7. ORGANIC EMISSIONS FOR A TYPICAL IRON FOUNDRY

Emission source	Organic emission factor (lb/ton)[a]	Normalized organic emission factor		Production capacity (ton/yr)[c]	Organic emissions (lb/yr)	Source contribution (percent of total)
		(lb/ton)[a]	(lb/net ton)[b]			
Gray and Ductile Iron Foundry[d]						
Cupola furnace	0.181	0.127	0.195	11,846	2,144.2	7.94
Electric arc furnace	0.347	0.104	0.160	5,077	1,761.7	6.52
Inoculation	0.0052	0.00083	0.0013	2,708	14.1	0.05
Pouring and cooling	0.136	0.136	0.209	16,923	2,301.5	8.52
Casting shakeout	1.228	1.228	1.889	16,923	20,781.5	76.96
Totals	-	1.596	2.455	-	27,003.0	100.00
Malleable Iron Foundry[e]						
Cupola furnace	0.181	0.127	0.195	15,077	2,728.9	7.94
Electric arc furnace	0.347	0.104	0.160	6,461	2,242.2	6.53
Pouring and cooling	0.136	0.136	0.160	21,538	2,929.2	8.53
Casting shakeout	1.228	1.228	1.889	21,538	26,449.2	77.00
Totals	-	1.595	2.453	-	34,349.5	100.00

[a] lb/ton melted metal.

[b] lb/net ton castings.

[c] Tons of melted metal/yr.

[d] Foundry capacity 11,000 net tons castings/yr; 16,293 tons melted metal/yr.

[e] Foundry capacity 14,000 net tons castings/yr; 21,538 tons melted metal/yr.

From Table 5-7, the annual organic emissions are approximately 13.5 tons/year for the typical gray and ductile iron foundry and approximately 17.2 tons/year for the malleable iron foundry. Since organic emissions due to metal inoculation is small compared to the other organic emissions, 0.05 percent, it is well within the band of uncertainty associated with the reported emissions factors and may be neglected yielding the same aggregate emissions factors for both the gray and ductile iron foundry and the malleable foundry.

In the foundry industry, particulate emissions including metallic aerosols are the major type of pollutant released to the atmosphere. Consequently, the pollution control devices used in foundries which include hoods, wet scrubbers, and baghouses are selected and designed primarily for particulate emission control and do not provide significant reduction in organic emissions. This situation is evidenced by comparing the emission factors upstream and downstream of a wet scrubber in a casting shakeout operation shown in Table 5-5. These emission factors indicated that the wet scrubber had a removal efficiency for organic compounds of only 16.6 percent which is substantially below the 90 to 95 percent removal efficiency typical of organic emissions control devices.

Because of the relatively small size of the typical foundry compared to other manufacturing plants which produce organic emissions, the installation of expensive organic emission control devices to meet environmental standards, if necessary, may have severe economic impact on the foundry. However, there are several modifications in foundry operating practice that may yield substantial reductions in organic emissions. For example, organic emissions from casting shakeout operations are highly dependent on mold size and cooling time. These two factors effect the temperature distribution within the sand molds at the time of casting shakeout. The higher the maximum temperature and the wider the temperature distribution in the mold at the time of shakeout, the higher the organic emissions generated (Baldwin, 1980). Therefore, significant reductions in organic emissions during casting shakeout may be achieved by merely increasing the cooling time for the molds, with virtually zero organic vapor emissions being obtained if the mold and metal casting were cooled to ambient conditions before shakeout. Although, the increased cooling time would increase the residual organics on the sand which is recycled for mold fabrication and would result in increased organic emissions during pouring, there are methods being developed to remove these residual organics from the recycled sand (Taylor, 1976) that could be implemented to reduce the attendant increased organic residuals on the sand.

The organic contaminants on the scrap metal is another potential source of organic emissions, particularly in the metal melting operation. Again, procedural modification such as segregation of metal scrap by organic contaminant content and the use of the higher organic contaminated scrap in cupola furnaces where organic combustion occurs may also provide substantial reduction in organic emissions.

Another way to reduce organic emissions without the installation of control devices is to convert from chemically-bonded sand molds to inorganically- and physically-bonded molds such as the CO_2-silicate molds and the pressure and magnetic field stabilized molds, respectively. With over 220 million pounds of chemical binders being consumed annually in the foundry industry, this represents potentially 110,000 tons/year of organic emissions. Fortunately, however, only a fraction of this reaches the atmosphere as organic emissions because a portion of the binder is oxidized to carbon monoxide and carbon dioxide, and a portion is graphitized where it may end up either in the iron or as a solid residue with the sand.

Still another method for reducing organic emissions is the increased use of new cupola furnace designs and operation procedures such as the hot air injection, oxygen enriched, and gased fired cupolas. These new cupolas provide increased combustion of organics and allow reduced use of coke, another source of organic emissions. If these new cupolas are used to process the metal scrap containing high levels of organic contaminants, significant reductions in organic emissions during melting operations may be realized.

Although a number of organic emission control options for the foundry industry have been identified, no economic or cost benefit analyses were performed in this study.

6.0 THE FERROALLOY INDUSTRY

Ferroalloys are materials which are added to iron and steel to give certain desired qualities in the finished product. They are used to deoxygenate; to improve malleability, ductility, and machinability; to increase strength and resistance to thermal stress; and to increase resistance to erosion and corrosion. Although ferroalloys can be relatively pure elements such as silicon, chromium, and manganese metal, the predominant alloys are mixtures of several elements such as ferrochromsilicon (FeCrSi), silicon-manganese-zirconium (SMZ) or ferrosilicon (FeSi).

6.1 OVERVIEW

Ferroalloy production is for the most part carried out in plants owned and operated separately from the iron and steel industry. Ferroalloy producers supply material to the steel industry and do not, themselves, produce the finished steel product. Steel companies do, however, produce some high carbon ferromanganese in blast furnaces but this process is considered part of the steel industry not the ferroalloy industry.

Table 6-1 gives the historical production and consumption of ferroalloys in the United States from 1945 through 1981. As can be seen from this table, since 1945 U.S. ferroalloy production has changed little while U.S. ferroalloy consumption has nearly doubled and ferroalloy imports have grown from 2.4 percent to over 65 percent of total U.S. consumption in this same period.

Based on these statistics, the picture of the ferroalloy industry is not one of a particularly healthy industry. Because of current trade and import pricing policies the industry reports few, if any, plans for new production furnaces or capacity expansions in the near future. The replacement of old, small furnaces by large, more efficient types and the closing of plants or the shutting down of some furnaces appears to be the present trend. As of December 30, 1982 there were only 8 ferroalloy furnaces --1- ferrochrome, 1- ferromaganese, 2- ferrosilicon, and 4-

TABLE 6-1. GENERAL STATISTICS ON FERROALLOYS

Year	Thousand net tons gross weights[a] Imports	Domestic consumption	Imports as percent consumption	Domestic production
1945[b]	39.2	1,607.1	2.4	1,665.7
1950	105.2	1,881.9	5.6	1,785.6
1955	81.6	2,132.9	3.8	2,224.6
1960	143.4	1,816.3	7.9	1,971.8
1965	351.4	2,518.5	14.0	2,585.1
1966	669.2	2,601.1	25.7	2,497.9
1967	342.1	2,294.2	14.9	2,526.2
1968	321.1	2,368.3	13.6	2,438.1
1969	433.0	2,477.2	17.5	2,437.1
1970	372.8	2,206.5	16.9	2,364.2
1971	387.8	2,260.8	17.9	2,163.4
1972	586.0	2,474.7	23.7	2,334.7
1973	716.7	3,008.4	23.8	2,306.4
1974	828.2	2,919.6	28.4	2,107.9
1975	859.0	2,097.7	40.9	1,758.7
1976[c]	993.0	2,276.1	43.6	1,741.6
1977[d]	1,013.2	2,293.6	44.2	1,618.4
1978[e]	1,285.9	2,526.3	50.9	1,452.8
1979[e]	1,309.3	2,509.4	52.2	1,628.9
1980[f]	1,090.2	2,043.5	53.3	1,302.8
1981[g]	1,436.3	2,100.1	68.4	1,273.7

[a] Ferromanganese, ferrochrome, ferrosilicon, and related metals.

[b] Data for years 1945 to 1975 from Westbrook and Daugherty, 1980.

[c] Jones, 1976.

[d] Schottman, 1977.

[e] Schottman, 1979.

[f] Schottman, 1980.

[g] Brown, 1981.

ferrosilicon metal -- out of a total of 85 standing furnaces operating in the United States (Brown, 1982).

Table 6-2 gives the most recent (1979) information on ferroalloy plants in the United States for which such information has been compiled. This list is essentially restricted to plants producing the primary ferroalloy products in submerged-arc furnaces. It does not include the plants producing specialty products (i.e., FeMo, NiCb, etc..), plants producing only CaC_2, or plants where production is by the electrolytic vacuum and alumino-thermic processes. Under current industry conditions with plants being sold and furnaces being retired, this listing has changed since it was compiled. Any further attempts to update this listing would be outdated before it could be published.

Most ferroalloys in the United States are produced in submerged-arc electric furnaces. Further refining of the furnace product or production of high purity materials can be done by exothermic processes, electrolytic processes, or vacuum and induction furnaces.

In submerged arc furnace operation which is continuous, the materials that typically include coal, coke, quartz (gravel), limestone, wood chips, iron turnings, manganese, and chromium ores are charged into the top of the furnace and the product and slag are tapped from the furnace bottom periodically. This product is then cast into a shallow mold to cool and solidify. After this cast product has cooled it is transported to the crusher where it is broken up and screened to sizes required by the customer.

6.2 ORGANIC MATERIAL INPUTS

On a macroscopic basis, organic material inputs for a typical ferroalloy manufacturing operation may include the following:

TABLE 6-2. SUBMERGED ARC FERROALLOY FURNACES IN THE UNITED STATES (1979)

Producer	Plant size[a]	Location	Products	Furnace types	No. of furnaces	Pollution control
Union Carbide, Ferroalloy Div.	E	Alloy, WV	Si, SiMn, CaSi, FeMn, FeCrSi	Open, hooded doors	11	Baghouse
	C	Sheffield, AL	50%, 75% FeSi	Semisealed	4	Scrubbers and baghouses
	A	Portland, OR	SiMn FeMn	Open Semisealed	1 2	Baghouse Scrubber
	E	Ashtabula, OH	$CaCO_2$, 50% FeSi	Semisealed	4	Scrubbers, baghouse on secondary
	E	Marietta, OH	50% FeSi SiMn, FeMn 50% FeSi, FeMn	Open Open Semisealed	1 2 6	Baghouse Scrubber Scrubbers
AIRCO alloys being sold to: SKW Trosberg AG	C	Niagara Falls, NY	FeCrSi, S,S, Pigs 75% FeSi	Open	3	Baghouse
MacAlloy, Inc.	D	Charleston, SC	FeCr	Open	2	Electrostatic precipitator
Compania Minera	B	Mobile, AL	SiMn	Sealed	1	Scrubber
Autlan, S.A. de C.V.	E	Calvert City, KY	FeMn, SiMn, FeCrSi, SS Pigs 50%, 75% FeSi	Open	8	Baghouse
Chromium Mining and Smelting Co.	B	Woodstock, TN	FeCr, 50% FeSi	Open, close hooded	4	Scrubbers
Foote Mineral Co.	B	Keokuk, IA	18% FeSi	Sealed	2	Scrubbers
	D	Graham, WV	50%, 75% FeSi	Open	3	Baghouse
	A	Cambridge, OH	Specialties	Open	2	Baghouse

(continued)

TABLE 6-2 (continued)

Producer	Plant size[a]	Location	Products	Furnace types	No. of furnaces	Pollution control
Hanna Mining Co.	A	Wenatchee, WA	Si, 50%, 75% FeSi	Open	3	Baghouse
	-	Riddle, OR	50% FeSi	Open	-	Baghouse
Interlake, Inc.	B	Selma, AL	Si	Open	2	Baghouse
	D	Beverly, OH	FeCr, FeCrSi, Si	Open	7	Baghouse
International Minerals and Chemicals - TAC Alloy	B	Bridgeport, AL	50% FeSi	Open	1	Baghouse
	A	Kimball, TN	50% FeSi	Open	1	Baghouse
Kawecki Berylco KBI, Cabot	B	Springfield, OR	Si	Open	3	Baghouse
Ohio Ferroalloys	C	Montgomery, AL	Si, 75% FeSi	Open	3	Baghouse
	E	Philo, OH	FeMn, SiMn	Open	3	Scrubbers
			50%, 75% FeSi	Open	6	Baghouse
	-	Powhattan, OH	Si	Open	4	Baghouse
Roane El. FCe. Englehardt	C	Rockwood, TN	FeMn, SiMn 50% FeSi	Open	7	Baghouse
Satralloy, Inc.	C	Stubenville,	FeCrSi, Ore-lime	Open	6	Baghouse
Chemetals Corp.		Kingwood, WV	FeMn			

Source: Westbrook and Daugherty, 1980.

[a] Plant size classification - installed capacity

A = up to 25 MW	C = 50 - 75 MW
B = 25 - 50 MW	D = 75 - 100 MW
	E = Over 100 MW

- Coal
- Coke
- Pitch
- Wood chips
- Raw material residuals (e.g., oil and other organics on scrap metal, turnings, mill scale)
- Carbon electrodes

Most of the organics enter the ferroalloy process in the feed materials that are charged to the submerged arc furnace. In addition to the organics in the feed material, the carbon electrodes which are consumed during the refining process are another organic input source to the furnace. Also, a carbon paste is used to plug the taphole and to line the lip from the taphole to the ladle.

6.3 ORGANIC EMISSIONS SOURCES AND CONTROL

Organic emissions may leave the process as fugitive emissions, if the air pollution capture system is ineffective. If the emissions are adequately captured at the furnace, they may be discharged through the particulate collection devices. For closed hood furnaces where combustion of furnace waste gas at the furnace is limited, flares downstream of scrubbers burn the gas as it is discharged.

There are basically two sources of organic emissions in the typical ferroalloy plant. The major source organic emissions is associated with the smelting operation in the submerged arc furnace. The second and generally minor organic emission source occurs at the furnace taphole during tapping and resealing operations.

Organic emissions from the submerged arc furnace not only depend on the amount of organic material charged to the furnace but also depend on the design of the furnace. There are four basic submerged arc furnace designs which are categorized primarily by the type of furnace top cover used. These furnace types are: totally open, close-hooded, mix-sealed, and sealed. In the totally open submerged arc furnace which is the predominant design in use in the United States, there is no cover of any kind on the furnace. Gases rising out of the furnace mix with ambient air and burn on the surface of the raw material charge to the furnace. The gases are then drawn into a collecting hood located 6 to 9 feet above the furnace. The close-hooded is very similar to the totally open furnace with the exception that moveable doors or panels are installed between the hood and the furnace top to restrict the air flow. The resulting lower air flow rate permits the use of smaller emission control equipment and decreases overall mass emissions compared to the totally open furnace. Also, with the reduced air flow, the gas temperature is substantially higher thereby increasing the probability that the more refractory organics will be destroyed.

In the mix-sealed furnace design, a water-cooled cover is installed directly on the furnace top. There are doors on the side of this cover to permit limited access to the furnace for stoking. Feed materials (mix) are added to the furnace through the annular spaces surrounding the electrodes passing through the cover. Sufficient mix is kept around the electrodes that, as long as a slight negative pressure is maintained beneath the cover, little furnace gas escapes the furnace cover and little air is drawn into the furnace. With this design, the very low air volumes exiting the furnace allow the use of much smaller pollution control equipment than that used for totally open and close-hooded furnaces. However, the mix-sealed furnace generally requires a secondary hood over the furnace to capture the emissions from the cover, primarily from the mix-seals. Although the furnace gases from this type of design can be used after scrubbing as plant fuel, in most cases the gases are flared. Combustion of any organic matter omitted by the mixed-sealed furnace is minimal.

The sealed furnaces use mechanical seals around the electrodes and sealed shoots through which the feed mix is added to the furnace. With this design, there is virtually no emission from the furnace cover and only a minimal secondary hood flow rate is required. Also, there is virtually no air leakage into the furnace; and, thus, combustion of the furnace gas does not occur. Again, after the gases are cleaned, they are usually flared.

In the ferroalloy industry, a carbon paste is normally used to plug the furnace taphole and to line the lip of the tapping spout. Heavy emissions which occur from the taphole and lip during the initial phase of a tap are a result of (1) burning the carbon plug out of the taphole, (2) fumes rising from the hot metal, and (3) vaporization of organics in the carbon used as a lip liner. Further emissions occur in this area when the taphole is plugged (carbon paste injected into the hole) and when the carbon added to the lip is heat cured. Most of these emissions, however, are of short duration and are partially captured by the taphole emission control system (when used) or by the main furnace control system. The emissions not captured exit the building through the roof monitors. Although the organic content of the taphole emissions could be high and could contain hazardous compounds, the total mass emission is probably low compared to the primary furnace emissions.

Emissions from transfer, cooling, grinding, and packaging of the product alloy will have a chemical analysis similar to the alloys being produced. One would expect very little if any organic component.

6.4 EMISSION FACTORS AND POLLUTION CONTROL

Organic emission factors for point sources within the ferroalloy industry are presented in Table 6-3. Also included in this table are estimates of total organic emissions by source for the ferroalloy industry based on 1981 production data. As pointed out in Section 6.3, there are basically only two significant sources of organic emissions in the typical ferroalloy plant, that is, gas discharged from the submerged arc furnace during the smelting operation and fugitive emissions from the carboneous taphole plug and lip liner. Since tapping emissions are considered minor

TABLE 6-3. ORGANIC EMISSIONS FROM POINT SOURCE WITHIN THE FERROALLOY INDUSTRY[a]

Emission source	Organic emission factor[b] (lb/ton)	Organic emission factor[b] (kg/MT)	EF Rating	U.S. annual production (1981)[c] (tons)	Organic emissions (tons)	References
Submerged-arc furnace						
Si metal						
Open type-uncontrolled	71.8	35.9	B	252,163	9,052.7	Westbrook, 1982
controlled[d]	51.6	25.8	B		6,505.8	Westbrook, 1982
50% FeSi						
Open type-uncontrolled	6.4	3.20	B	537,578	1,720.2	Westbrook, 1982
controlled[d]	4.4	2.20	B		1,182.7	Westbrook, 1982
Covered type-uncontrolled	15.0	7.48	B	64,006	478.8	Westbrook, 1982
controlled[e]	4.48[g]	2.74	B		143.4	Westbrook, 1982
	(4.26)[h]	(2.13)				
HC FeMn						
Open type-uncontrolled	15.9	7.96	B	116,546	927.7	Westbrook, 1982
controlled	3.72	1.86	B		216.8	Westbrook, 1982
Covered type-uncontrolled	1.38	0.69	B	76,144	52.5	Westbrook, 1982
controlled[f]	0.80	0.40	B		30.5	Westbrook, 1982
FeCr/FeCrSi						
Open type-uncontrolled	11.2	5.58	D	202,356	1,129.1	Estimated[i]
controlled	4.06	2.03	D		410.8	Estimated[i]
Covered type-uncontrolled	8.18	4.09	D	24,896	101.8	Estimated[i]
controlled	3.14	1.57	D		39.1	Estimated[i]
Tapping	D.N.A.[j]	-	-	-	-	
Totals: uncontrolled	21.1[k]	10.6		1,273,689	13,462.9	
controlled	13.4[k]	6.70		1,273,689	8,529.1	
Overall capture efficiency:					36.6%	

[a] Does not include low boiling point (C_1-C_8) hydrocarbons.

[b] Emissions per ton or metric ton of ferroalloy produced.

[c] Assumes open and covered furnace production for a ferroalloy product in same ratio as the open and covered furnace capacities available for that product.

[d] Emission control via baghouse.

[e] Emission control via wet scrubber with scrubber flare and secondary fume baghouse.

[f] Emission control via wet scrubber.

[g] Assumes no destruction of organics by the scrubber flare and 13 percent capture in secondary fume baghouse.

[h] Assume 100% destruction of organics by the scrubber flare and 13 percent capture in secondary fume baghouse.

[i] Mean of emission factors for 50% FeSi and HC FeMn ferroalloy production.

[j] Data not available.

[k] Overall ferroalloy organic emission factors based on 1981 production and product distribution.

compared to furnace emissions (Westbrook and Daugherty, 1980) and no field sampling data were available, an emission factor for this source was not estimated.

Separate organic emission factors are presented for the two major types of submerged arc furnace. Process analysis and field testing (Westbrook and Daugherty, 1980) indicate significant differences in organic emissions based on furnace type. The open type furnace (totally open and close-hooded) which represent about 80 percent of U.S. ferroalloy submerged-arc furnace annual production capacity permits partial combustion of the organics in the top of the furnace, producing less organic emissions than the covered (sealed and mixed sealed) furnace type. The emission factors presented in Table 6-3 by type of ferroalloy product are based on measurements upstream and downstream of the pollution control devices on the furnaces.

From Table 6-3, the total estimated organic emissions from ferroalloy industry based on 1981 production data is 8,529.1 tons per year. Implicit in this estimate is the assumption that the total ferroalloy production was apportioned between the open-type submerged arc furnace and the sealed-type submerged arc furnace in the same proportion as their estimated total production capacities. With this assumption the effective aggregate organic emission factor for the ferroalloy industry is estimated to be 13.4 lb/ton of ferroalloys produced.

In the ferroalloy industry, the primary pollution control devices in use are fabric filters (baghouses), wet scrubbers (high and medium energy), and electrostatic precipitators. The baghouse appears to be the most frequently used pollution control device with wet scrubbers being used almost as frequently. Only one plant is reported using the electrostatic precipitator as its primary control device. Most ferroalloy plants using a secondary collection system to control secondary emissions from covered furnaces and fugitive emissions from tapping operations employ baghouse collection devices because of lower capital and operating costs compared to wet scrubbers and electrostatic precipitators for this application.

Generally, the gases leaving the pollution control devices are flared to achieve further destruction of pollutants. However, no data were available on the effectiveness of flaring the gases in destroying organic emissions.

In an EPA-sponsored Research Triangle Institute study (Contract No. 68-02-2630), the organics removal efficiency of five wet scrubber pollution control devices, as determined from analysis of scrubber inlet and outlet water, ranged from 16 percent to about 96 percent with an average removal efficiency of 65.3 percent (Westbrook and Daugherty, 1980). Where baghouses were used, 13 to 64.5 percent of organics generated in the furnaces were captured.

Unlike electric arc furnace steelmaking operations in the steel plants and iron melting operations in iron foundry where the predominant organic material input to the furnace is the oil and organic material content of the scrap metal, the ferroalloy smelting (refining) operations in submerged arc furnaces use significantly more organic material such as wood chips, coal, and pitch in the furnace charge. Therefore, the substitution of clean raw materials (scrap), used to reduce organic emissions in the iron and steel and iron foundry industries, would probably not significantly reduce the organic emissions from the submerged arc furnace in ferroalloy manufacturing.

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APPENDIX A

BLAST FURNACE: TOP ORGANIC EMISSIONS

Source

1. Leakage around bells (continuous)
2. Opening and closing of bells during burden charging (discrete, regular intervals)
3. Bleeder valve opening to release gas pressure buildup from this source on the average is negligible compared to the first two sources.

Assumptions

1. Effluent gas in top of BF contains 0.2% CH_4 (Vol,dry) (methane) (McGannon, 1971; p. 94)
2. Organics (primarily lubricants) on mill scale and mill scrap are partially flashed off in the large bell hopper and discharged to the atmosphere via bell leaks and opening of the small bell during charging (Serne and Wilson, 1978; p. 8-88).
3. Blast furnace consumption of mill scale and scrap (American Iron and Steel Institute, 1982; p. 63).

   Scrap = 0.058 lb/lb iron produced
   Scale = 0.044 lb/lb iron produced
4. Mill scale typically contains 0.1 to 2% (wt) (Serne and Wilson, 1978; pg. 8-19) with an average of ~ 0.6% (wt) (Serne and Wilson, 1978; p. 8-86) but reported as high as 25% (wt) (Serne and Wilson, 1978; p. 8-19). Since mill practice is to recycle the mill scale with low lubricant content to the center plant and the high lubricant content scale to dumps and the BF or BOF, a value of 1% (wt) lubricant on the mill scale sent to the BF is used.
5. Since mill scrap consists mainly of material (debris, trimings, and off spec product) from mill finishing operations, we

assumed the lubricant content of the scrap is the same as that of the finished product which is made up of rolling and coating oils (Serne and Wilson, 1978; p. 8-84). Mill product contains about 0.3 gal/ton oil.

6. Blast furnace production for 1981 (American Iron and Steel Institute, 1982; p. 61) is 73,570,000 net tons of iron produced.

7. Bell leakage per BF is (Jablin et al., 1978; p. 74)
   Gas Leakage (cfm) = 500 + 1500N
   where N = number of years bells in service, years

8. Average BF bell service life in U.S. is 2.5 years (Jablin et al., 1978; p. 76) i.e., N = 2.5 years (N = 6.9 years in Japan)

9. Since gas leakage equation in assumption is based on Japanese BF's where operating gas pressures are higher than in the U.S., a correction factor is needed.

$$\frac{\text{Avg. pressure U.S.}}{\text{Avg. pressure Japan}} = \frac{4.75}{15.72} = 0.302$$

10. BF operating gas pressure in 4.5 to 5 psig.

11. Gas temperature in top of BF at the bells is 250°F to 700°F with typical temperature of 300°F (McGannon, 1971; p. 94).

12. Lubricant on mill scale is essentially rolling oils and on mill scrap is coating oil.

13. Lubricant composition for molecular weight estimation is 20% paraffin ($C_{22}H_{46}$), 50% alkyl cyclohexane ($C_{26}H_{52}$), and 30% alkyl benzene ($C_{26}H_{46}$). This yields an average molecular weight of 350 lb/lb-mole (Rossini et al., 1953; p. 410).

14. Blast furnace production capacity for 160 furnaces is estimated at 130 x 10^6 net tons/year (U.S. Environmental Protection Agency, 1982; pp. 314-320) for 1976.

15. Volume of large bell hopper (assume average) is 1845 ft. 3 (for 30' 10" ϕ hearth) (McGannon, 1971; p. 430).

Bell Leakage

Based on the analysis in (Jablin et al., 1978; pp. 74-78) the estimated average gas leakage for BF bells in the U.S. is:

$$\text{Gas Leakage} = 500 + 1500\ (6.9)\ \frac{4.75}{15.72}\ \frac{2.5}{6.9}$$

$$= 2161 \text{ cfm/BF}$$

$$\text{Annual Gas Leakage} = (2161 \text{ cfm})(60)(24)(365) = \underline{\underline{1.14 \times 10^{9} \text{ft}^{3}\text{/yr/BF}}}$$

Lubricant Loading

Lubricants are introduced into the BF as primarily rolling and coating oils on the mill scale and mill scrap charged. To simplify the calculations, it is assumed the rolling oil enters on the mill scale and the coating oil on the mill scrap.

$$\text{Mill Scale} = \left(\frac{0.044 \text{ lb scale}}{\text{lb iron}}\right) \times \left(\frac{0.01 \text{ lb oil}}{\text{lb scale}}\right) = 4.4 \times \frac{10^{-4} \text{ lb oil}}{\text{lb iron}}$$

$$\text{Mill Scrap} = \left(\frac{0.058 \text{ lb scrap}}{\text{lb iron}}\right) \times \left(\frac{0.0012 \text{ lb oil}}{\text{lb scrap}}\right) = 7.0 \times \frac{10^{-5} \text{ lb oil}}{\text{lb iron}}$$

$$\text{Total Lubricant} = 44 \times 10^{-5} + 7.0 \times 10^{-5} = 51 \times \underline{\underline{\frac{10^{-5} \text{ lb oil}}{\text{lb iron}}}}$$

Lubricant Vaporized in Bell Hopper

Based on the data in Serne and Wilson (1978); Appendix, Table VII, on the vaporization of typical lubricants was estimated for the average residence time of the material in the large bell hopper and a typical hopper temperature of 300°F. (See Appendix E herein)

$$\text{Rolling Oil (@ 300°F):} \quad 0.014 \ \frac{\text{lb vaporized}}{\text{lb oil-minute}}$$

$$\text{Coating Oil (@ 300°F):} \quad 0.022 \ \frac{\text{lb vaporized}}{\text{lb oil-minute}}$$

Assume BF charging follows the sequence OCCOSCC/(McGannon, 1971; p. 466) with the small bell opening about 600 times per day and the large bell 80 times per day (Jablin et al., 1978; p. 88).

$$\text{BF Charging Cycle} = \frac{(60\ \text{min/hr})(24\ \text{hr/day})}{80\ \text{charges/day}} = 18\ \frac{\text{min}}{\text{charge}}$$

Based on the assumed charging sequence above the average residence time of the scale and scrap in the large bell hopper is about 15 minutes.

$$\text{Rolling Oil Vaporized} = (0.014\ \frac{\text{lb/lb}}{\text{min}})(15\ \text{min}) = 0.33\ \frac{\text{lb vapor}}{\text{lb oil}}$$

$$\text{Coating Oil Vaporized} = (0.022\ \frac{\text{lb/lb}}{\text{min}})(15\ \text{min}) = 0.33\ \frac{\text{lb vapor}}{\text{lb oil}}$$

Total Lubricant Vaporized =

$$(4.4 \times 10^{-4}\ \frac{\text{lb oil}}{\text{lb iron}}) \times (\frac{0.21\ \text{lb vapor}}{\text{lb oil}}) + (7 \times 10^{-5}\ \frac{\text{lb oil}}{\text{lb iron}})$$

$$\times (\frac{0.33\ \text{lb vapor}}{\text{lb oil}})$$

$$\text{Total Lubricant Vaporized} = 1.2 \times 10^{-4}\ \frac{\text{lb vapor}}{\text{lb iron produced}}$$

Lubricant Vaporized in Top of Blast Furnace

The remaining oil on the scale and scrap are vaporized in the top of the blast furnace and is mixed with the off-gas. Some of these organics escape to the atmosphere through the bell leaks and when large bell is opened.

$$\text{Lubricant Vaporized in Top BF} = 51 \times 10^{-5} = 12 \times 10^{-5}$$
$$= 39 \times 10^{-5}\ \frac{\text{lb vapor}}{\text{lb iron produced}}$$

Blast Furnace Off-Gas Rates

From McGannon (1971; p. 457) the off-gas rate from a typical blast furnace (28 ft. in diameter) is 63,500 scf/2000 lb iron produced (stan-dard conditions are: 60°F and 1.0 atmosphere). The above is on a dry basis. Moisture is about 3,300 scf/2000 lb iron.

$$\text{Gas Rate (dry)} = \frac{63{,}500\ \text{scf}}{2000\ \text{lb iron}} = 31.75\ \frac{\text{scf}}{\text{lb iron produced}}$$

$$\text{Gas Rate (wet)} = \frac{66{,}800\ \text{scf}}{2000\ \text{lb iron}} = 33.40\ \frac{\text{scf}}{\text{lb iron produced}}$$

Organic Composition in BF Top Gas

Methane in BF off-gas in about 0.2% (vol) (McGannon, 1971; p. 94).

Methane present =

$$\left(31.75\ \frac{\text{scf gas}}{\text{lb iron}}\right) \times \left(0.002\ \frac{\text{scf } CH_4}{\text{scf gas}}\right) \times \left(\frac{1\ \text{lb-mole } CH_4}{379\ \text{scf } CH_4}\right) \times \left(16\ \frac{\text{lb } CH_4}{\text{lb mole } CH_4}\right)$$

$$\text{Methane present} = 26.5 \times 10^{-4}\ \frac{\text{lb } CH_4}{\text{lb iron produced}}$$

$$CH_4 \text{ in BF Off-gas} = \frac{26.5 \times 10^{-4}\ \text{lb } CH_4/\text{lb iron}}{31.75\ \text{scf off-gas/lb iron}}$$

$$= 83.6 \times 10^{-6}\ \frac{\text{lb } CH_4}{\text{scf off gas}}$$

$$\text{Oil Vapor in Off-gas} = \frac{39 \times 10^{-5}\ \text{lb/lb iron}}{31.75\ \text{scf off-gas/lb iron}}$$

$$= 12.3 \times 10^{-6}\ \frac{\text{lb vapor}}{\text{scf off-gas}}$$

$$\text{Total Organics in Off-Gas} = (83.6 + 12.3) \times 10^{-6}$$

$$= 95.9 \times 10^{-6}\ \frac{\text{lb organics}}{\text{scf off-gas}}$$

Blast Furnace Bell Organic Emissions via Leaks

$$\text{Gas Leak (scf)} = (1.14 \times 10^{9}\ \text{scf/year/BF}) \times \frac{(760^\circ K)}{(520^\circ K)}$$

$$= 1.67 \times 10^{9}\ \text{scf/year/BF}$$

$$\text{Bell Organic Leakage} = \left(1.67 \times 10^{9}\ \frac{\text{scf/year}}{\text{BF}}\right)\left(95.9 \times 10^{-6}\ \frac{\text{lb organics}}{\text{scf off-gas}}\right)$$

$$= 160 \times 10^{3}\ \text{lb organics/year/BF}^{*}$$

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*Assumes blast furnace utilization factor (i.e., service factor) of 100%.

Based on 160 BF identified (U.S. Environmental Protection Agency, 1982; pp. 314-320), the total bell organics leakage is at 100% utilization:

$$\text{Total bell organics leakage} = (160 \times 10^3 \text{ lb organics/year})(160)$$

$$= 25.6 \times 10^6 \ \frac{\text{lb organics}}{\text{year}}^{*}$$

Organic Emission Factor for BF Bell Leaks

From (American Iron and Steel Institute, 1982; p. 61) the 1981 blast furnace iron production was 73,570,000 net tons.

$$\text{BF Utilization} = \frac{73{,}570{,}000}{130{,}000{,}000} = 0.566$$

$$\text{EF (Bell Leaks)} = \frac{(25.6 \times 10^6 \text{ lb organics}) \times (0.566)}{73{,}570{,}000 \text{ ton iron}}$$

$$= 0.197 \ \frac{\text{lb organics}}{\text{ton iron}} \quad \left(0.099 \ \frac{\text{kg organics}}{\text{(MT iron)}} \right)$$

Volume of Gas Released during Bell Opening

Assumed gas composition (McGannon, 1971; p. 94)

CO_2	11.5% (Vol d.b.)
N_2	59.8% (Vol d.b.)
CO	27.5% (Vol d.b.)
H_2	1.0% (Vol d.b.)
CH_4	0.2% (Vol d.b.)

H_2O 4.9% (Vol) of total gas (McGannon, 1971; p. 457, Fig. 15-31)

$$\overline{MW} = 0.951 \times [0.115(44) + 0.598(28) + 0.01(2) + 0.002(16)] + 0.049(18)$$

$$\overline{MW} = 21.67 \text{ lb/lb mole}$$

$$\text{Gas Density} = \frac{21.67 \text{ lb/lb mole}}{(359 \text{ cf/lb-mole}) \left(\frac{760}{492}\ \frac{14.7}{19.7}\right)} = 0.0524 \text{ lb/cf}$$

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*Assumes blast furnace utilization factor (i.e., service factor) of 100%.

Gas in Bell Hopper = (1845 cf)(0.0524 lb/cf)

= 96.7 lb

Volume of Gas in Hopper (@ 1 atm and 300°F)

$$= \frac{(\quad 96.7\ \text{lb} \quad)}{(21.67\ \text{lb/lb-mole})} \times \left(359\ \frac{\text{cf}}{(\text{lb-mole})}\right) \times \frac{(760°\text{R})}{(492°\text{R})}$$

= 2475 cf

Volume Gas Released = (2475 cf - 1845 cf) 80 cycle/day

= 50,400 cf/day

Amount VOC Released = (50,400 cf/day)(0.951)(0.002)

= 95.9 cf CH_4/day/BF = 62.1 scf CH_4/day/BF

Total VOC Released = (95.9 cf/day/BF) x (365 day/year) x (160 BF)

$$= \frac{(5.60 \times 10^6\ \text{cf/year}) \times \frac{(493°\text{R})}{(760°\text{R})} \times (16\ \text{lb/lb-mole})}{(359\ \text{scf/lb-mole})}$$

$$= 162 \times 10^3\ \frac{\text{lb } CH_4}{\text{year}} \quad (@\ 100\%\ \text{Utilization})$$

For 1981 BF Utilization of 0.566 and 73,570,000 net tons of iron produced, the EF for bell opening is:

$$\text{EF(Bell Opening)} = \frac{(162 \times 10^3\ \text{lb organics}) \times (0.566)}{73{,}570{,}000\ \text{NT iron}}$$

$$= 0.00125\ \frac{\text{lb organics}}{\text{ton iron}} \qquad \left(0.00249\ \frac{\text{kg organics}}{(\text{MT iron})}\right)$$

Total VOC Emission Factor for Top of Blast Furnace

$$\text{EF} = [\overset{\text{Leaks}}{0.197} + (\overset{\text{Opening}}{0.240 + 0.00125})] = 0.438\ \frac{\text{lb organics}}{\text{ton iron}} \qquad \left(0.219\ \frac{\text{kg organics}}{(\text{MT iron})}\right)$$

APPENDIX B

BLAST FURNACE: FUGITIVE ORGANIC EMISSIONS

Sources

1. Leakages in ducts, valves, etc..
2. Venting operations and abnormal BF operations (e.g., slips)

Assumptions

1. Difference between amount of blast furnace gas produced and the amount consumed throughout the plant, corrected for the amounts lost to the atmosphere around the bells (already calculated for BF top VOC emissions), is the amount of fugitive emission in gas distribution and other losses to the atmosphere.
2. Blast furnace gas consumed in 1981 is 3,336,392 x 10^6 scf (standard conditions 60°F and 1 atmosphere) (American Iron and Steel Institute, 1982; p. 73).
3. Blast furnace gas consumed is assumed to be reported on a day basis (moisture free).
4. Blast furnace gas produced is 63,500 scf(db)/net ton iron produced (McGannon, 1971; p. 457).
5. Annual BF gas leakage around the bells is (1.67 x 10^9 scf/BF) (160 BF) = 267 x 10^9 scf/year
6. Annual BF gas vented during bell opening is (50,400 cf/day/BF) (520°R/760°R) x (365 day/yr) x (160 BF) = 2.0 x 10^9 scf/year
7. Blast furnace utilization factor for 1981 is 0.566

   (73,570,000/130,000,000) = 0.566
8. Blast furnace production for 1981 is 73,570,000 net tons of iron (American Iron and Steel Institute, 1982; p. 61).
9. Total organics in blast furnace off-gas is:

   $$95.9 \times 10^{-6} \ \frac{\text{lb organics}}{\text{scf off-gas}} \quad \text{(Appendix A)}$$

Organic Emission Factor for Blast Furnace Fugitive Emissions

$$\text{BF Gas Produced} = \left(63{,}500\ \frac{\text{scf}}{\text{ton iron}}\right) \times \left(73{,}570{,}000\ \frac{\text{ton iron}}{\text{year}}\right)$$

$$= 4.67 \times 10^{12}\ \text{scf/year}$$

$$\text{BF Gas Released} = [4.67 - 3.34 - 0.167 \times (0.566) - 0.002 \times (0.566)] \times 10^{12}$$

$$= 1.18 \times 10^{12}\ \text{scf/year}$$

$$\text{EF (Fugitive)} = \frac{(1.18 \times 10^{12}\ \text{scf/year}) \times (95.9 \times 10^{-6}\ \text{lb organics/scf})}{73{,}570{,}000\ \text{tons iron}}$$

$$= 1.54\ \frac{\text{lb organics}}{\text{ton iron}} \qquad \left(0.77\ \frac{\text{kg organics}}{\text{MT iron}}\right)$$

APPENDIX C

BASIC OXYGEN PROCESS: ORGANIC EMISSIONS

Source

1. Hot metal charging

Assumptions

1. Typical BOP yield of steel is 85% for open hood pollution control system and 87% for a closed hood system (Coy et. al., 1978; pg. 10).
2. Typical scrap charge is 30% of total iron-bearing charge and molten iron 70%.
3. From actual emission measurements made to standard procedures and actual operating date the following emission factors were determined (Westbrook, 1980; pg. 177-196).

BOF 0.00328 lb organics/ton scrap charged

Q-BOP 0.0692 lb organics/ton scrap charged

BOF Emission Factor

$$\left(0.00328\ \frac{\text{lb Organics}}{(\text{ton scrap})}\right) \times \left(0.3\ \frac{\text{ton scrap}}{(\text{ton charged})}\right) \times \left(\frac{1}{0.85}\ \frac{\text{ton charged}}{\text{ton steel produced}}\right)$$

$$= \underline{\underline{0.00116\ \frac{\text{lb Organics}}{\text{ton steel produced}}}} \quad \underline{\underline{\left(0.000678\ \frac{\text{kg Organics}}{(\text{MT steel produced})}\right)}}$$

Q-BOP Emission Factor

$$\left(0.0692\ \frac{\text{lb Organics}}{\text{ton scrap}}\right) \times \left(0.3\ \frac{\text{ton scrap}}{\text{ton charge}}\right) \times \left(\frac{1}{0.85}\ \frac{\text{ton charged}}{\text{ton steel produced}}\right)$$

$$= \underline{\underline{0.0244\ \frac{\text{lb Organics}}{\text{ton steel produced}}}} \quad \underline{\underline{\left(0.0122\ \frac{\text{kg Organics}}{(\text{MT steel produced})}\right)}}$$

APPENDIX D

FINISHING MILLS: HYDROCARBON EMISSIONS

Source

1. Cold reduction mills
2. Hot strip mills with application of rolling oils
3. Hot strip mills with no application of rolling oils

Assumptions

1. Typical cold reduction tandem mill capacity in the U.S.A. is 1.28 x 10^6 ton/yr (1.16 x 10^6 MT/yr) (Mackus and Joshi, 1981; p. 6-5).

2. Typical hot strip mill production capacity in the U.S.A. for both the application and no application of rolling oils is (Mackus and Joshi, 1981; pp. 6-13).

   2.58 x 10^6 ton/yr (2.34 x 10^6 MT/yr)

3. Typical cold strip (reduction) mill lubricant consumption is 2.35 lb lub/ton processed steel (1.18 kg/MT) (Mackus and Joshi; 1981; p. 6-7).

4. Average amount of lubricant volatilized in typical cold strip mill is 23.9% (wt) of lubricant used (Mackus and Joshi, 1981; p. 6-9).

5. Typical hot strip mill (with and without rolling oil application), i.e., with RO and without RO respectively, lubricant consumption is (Mackus and Joshi, 1981; p. 6-13).

   1.73 lb lub/ton processed steel (0.85 kg/MT) w RO
   1.47 lb lub/ton processed steel (0.735 kg/MT) w/o RO

6. Average amount lubricant volatized in typical hot strip mill (with and without rolling oil application) is (Mackus and Joshi, 1981; pp. 6-15).

   7.9% of lubricant used w RO
   1.7% of lubricant used w/o RO

7. The average mill production rates upon which lubricant consumptions are based is:

   60% of annual cold mill rolling capacity
   76% of annual hot strip mill rolling capacity

8. On the average 50% of hot strip mills use rolling oils.

9. Annual total (design) capacity of (Mackus and Joshi, 1981; pp. 7-2 and 7-3).
   Cold Reduction Mills in 26 x 10^6 ton/year and
   Hot Strip Mills is 67 x 10^6 ton/year

10. Steel processed in the cold reduction mills and hot strip mills make one pass through the rolling mills.

Cold Strip (Reduction) Mills

Lubricant Usage =

(2.35 lb/ton) x (1.28 x 10^6 ton/yr) x (0.60)(1 ton/2000 lb)
= 902.4 ton lubricant/yr (818.7 MT/yr)

$$\text{Lubricant Volatilized} = (902.4\ \text{ton/yr}) \times \left(0.239\ \frac{\text{ton vol}}{\text{ton lub}}\right)$$

= 215.7 ton Vol/yr (195.7 MT Vol/yr)

$$EF = \frac{(215.7\ \text{ton Vol/yr})(2000\ \text{lb/ton})}{(1.28 \times 10^6\ \text{ton/yr})(0.60)}$$

$$EF = 0.562\ \frac{\text{lb Volatiles } (CH_4)}{\text{ton steel processed}} \qquad \left(0.281\ \frac{\text{kg}}{\text{MT}}\right)$$

Hot Strip Mills with Rolling Oil Application

Lubricant Usage =

(1.73 lb/ton) x (2.58 x 10^6 ton/yr) x (0.76) x (1 ton/2000 lb)
= 1696.1 ton lubricant/yr (1538.7 MT/yr)

Lubricant Volatilized = (1696.1 ton/yr) x (0.079)
= 134.0 ton Vol/yr (121.6 MT Vol/yr)

$$EF = \frac{(134.0\ \text{ton/yr}) \times (2000\ \text{lb/ton})}{2.58 \times 10^6\ \text{ton/yr})(0.76)}$$

$$= 0.137\ \frac{\text{lb Volatiles } (CH_4)}{\text{ton steel processed}} \quad (0.0683\ \frac{\text{kg}}{\text{MT}})$$

Hot Strip Mills without Rolling Oil Application

Lubricant Usage = (1.47 lb lub/ton) x (2.58 x 10^6 ton/yr) x (0.76) x (1 ton/2000 lb) = 1441.2 ton lubricant/yr (1307.4 MT/yr)

Lubricant Volatilized = (1441.2 ton/yr) x (0.017)
= 24.5 ton volatiles/yr (22.2 MT/yr)

$$EF = \frac{(24.5\ \text{ton/yr}) \times (2000\ \text{lb/ton})}{(2.58 \times 10^6\ \text{ton/yr}) \times (0.76)}$$

$$= 0.0250\ \frac{\text{lb Volatiles } (CH_4)}{\text{ton steel processed}} \quad 0.0125\ \frac{\text{kg volatiles } (CH_4)}{\text{MT steel processed}}$$

Average EF for Hot Strip Mill

EF = (0.5)(0.137) + (0.5)(0.025)

$$= 0.081\ \frac{\text{lb volatile } (CH_4)}{\text{ton steel processed}} \quad 0.0405\ \frac{\text{kg volatiles } (CH_4)}{\text{MT steel processed}}$$

APPENDIX E
LUBRICANT EVAPORATION RATE

Evaporation Rate

$$(1)\quad \frac{dn}{dt} = A^{*}T \exp \frac{[-(BE)]}{[kT]}$$

where A* = material specific constant
T = Absolute temperature °K
K = Boltzmann constant
(BE) = binding energy/molecule
N = member of molecules evaporated
t = time

for moles evaporated the equation becomes

$$(2)\quad \frac{dn}{dt} = AT \exp \frac{[-Hv]}{[RT]}$$

where N = moles evaporated
R = gas constant (1.987 kcal/g-Mole°K)
Hv = binding energy/mole

for the purpose of using multiple linear regression analysis to estimate values for A and Hv from experimental evaporation data a more general form of equation (2) is used, equation (3):

$$(3)\quad \frac{dn}{dt} = AT^{\alpha} \exp \frac{[-Hv]}{[RT]}$$

Taking the natural log of both sides of equation (3), we get equation (4):

$$(4)\quad \ln \frac{dn}{dt} = \mathrm{lu}\ A + \alpha \ln T - \frac{Hv}{R}\,\frac{1}{T}$$

Now using equation (4) and experimental data on oil and grease weight loss as a function of temperature (Serne and Wilson, 1978; Appendix, Table VII), we can estimate the amount of lubricant vaporized in the blast furnaces large bell hopper from the metal scrap and mill scale charge.

For dn/dt expressed in g-moles/minute and T in °K, multiple linear regression of the data yields

Lubricant	lu A	α	-(Hv/R)	(dn/dt)300°F
Rolling Oil	23.2551	-1.917	-6737.7	0.01356
Coating Oil	8.1829	-0.676	-3336.2	0.02216
Hydraulic Fluid	7.1573	-0.491	-3617.0	0.01247
Grease	62.3391	10.051	-1354.9	0.008289

OIL & GREASE WEIGHT LOSS FROM LABORATORY TESTS

	T °F	1000/T°K	% Weight loss after 30 mins.
Grease	205°F	2.709	4.1%
	271°F	2.464	14.8%
Coating	203°F	2.717	22.9%
	279°F	2.438	54.1%
Hydraulic Oil	203°F	2.717	11.4%
	293°F	2.392	34.7%
Rolling Oil	203°F	2.717	5.1%
	293°F	2.392	35.7%
		(2.249)	100.0%

APPENDIX F

APPENDIX REFERENCES

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